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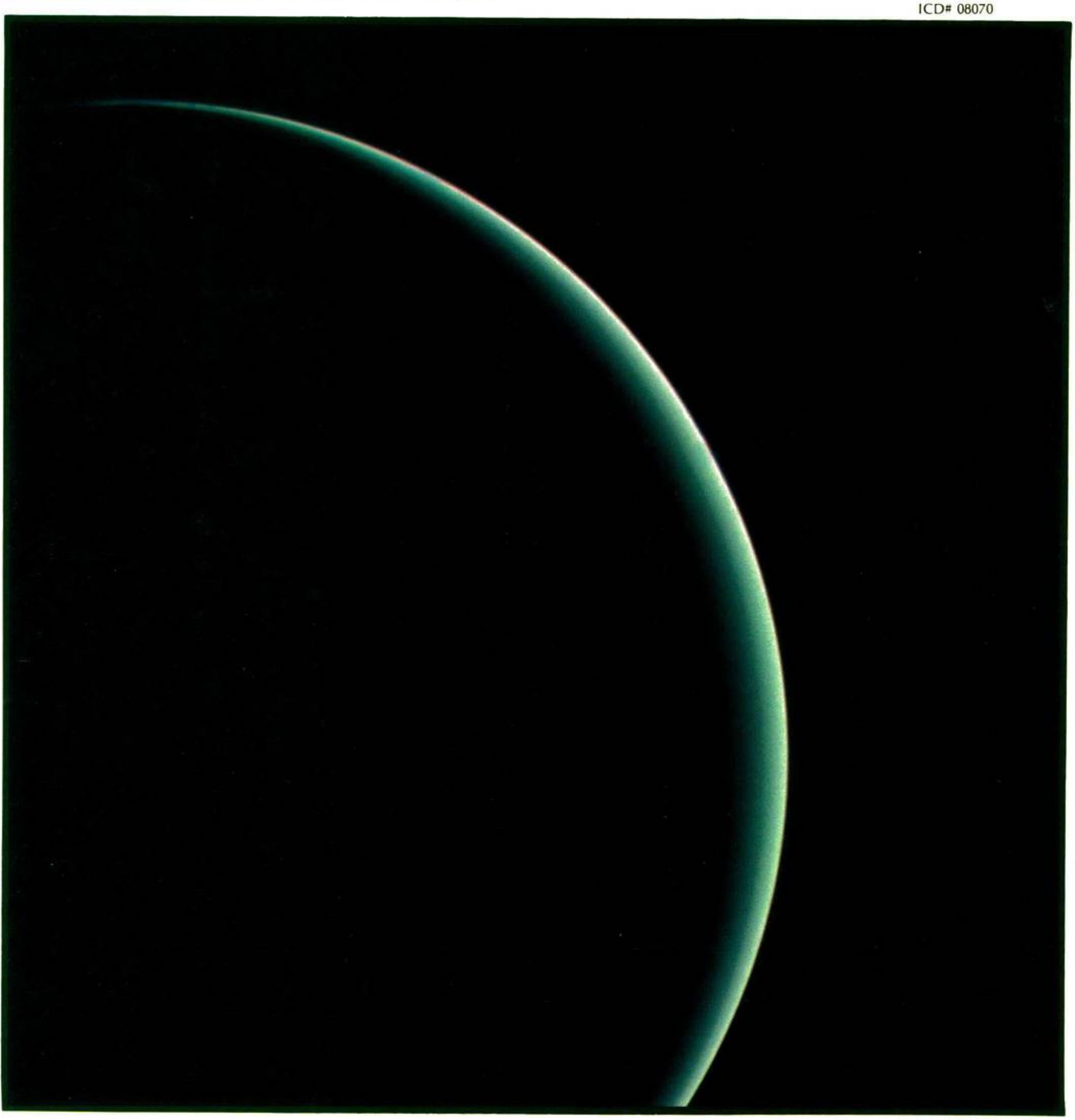

Looking Back at Uranus

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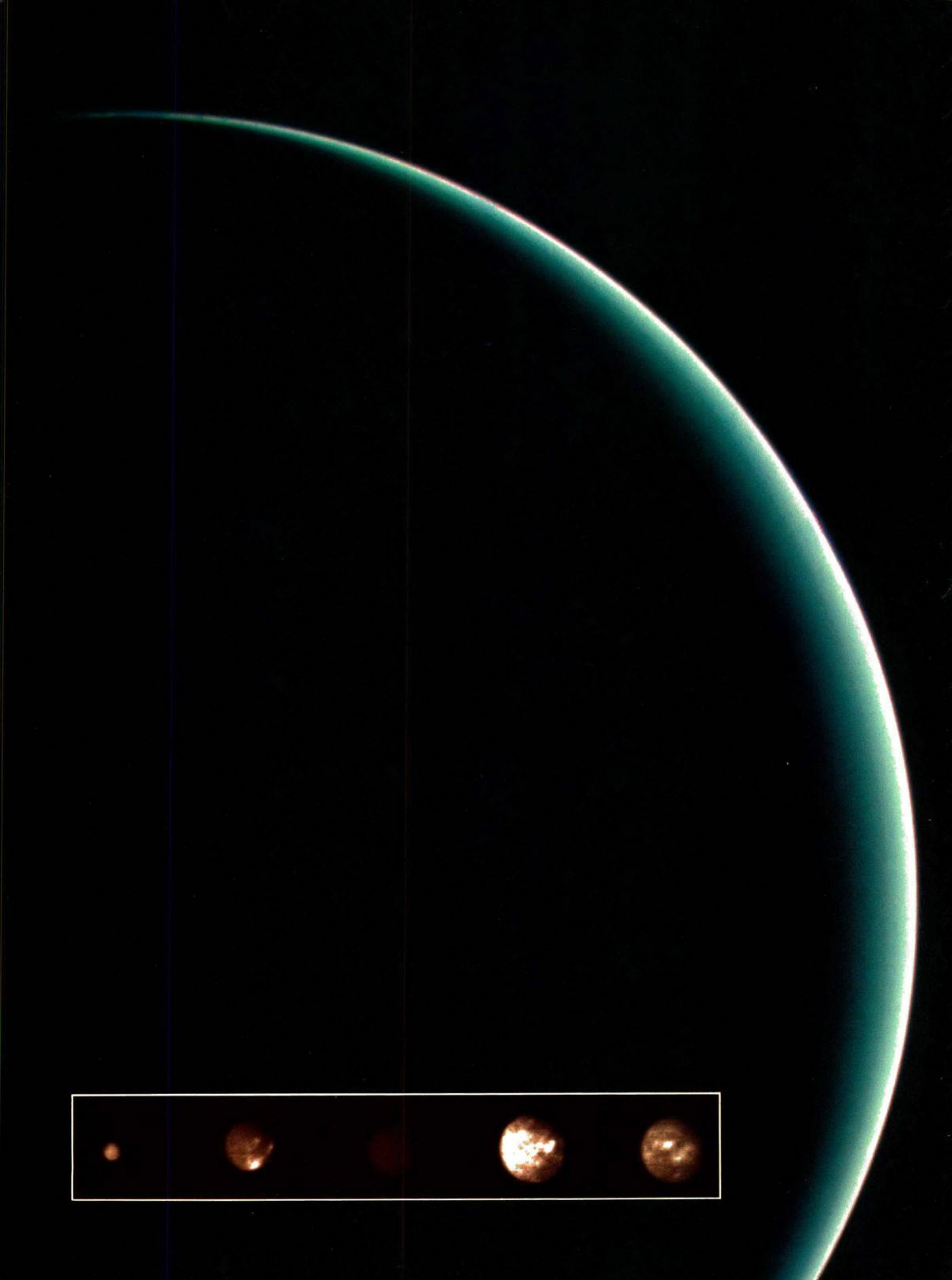

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Cover: Looking back, Voyager's cameras recorded the blue-green crescent of Uranus. This color results from methane in Uranus' atmosphere: the gas absorbs red light in the incident sunlight, leaving the green and blue to dominate. The limb is whitish due to high haze in the atmosphere. These pages: The five largest satellites of Uranus (from left to right) are Miranda, Ariel, Umbriel, Titania, and Oberon. JPL/NASA photos.

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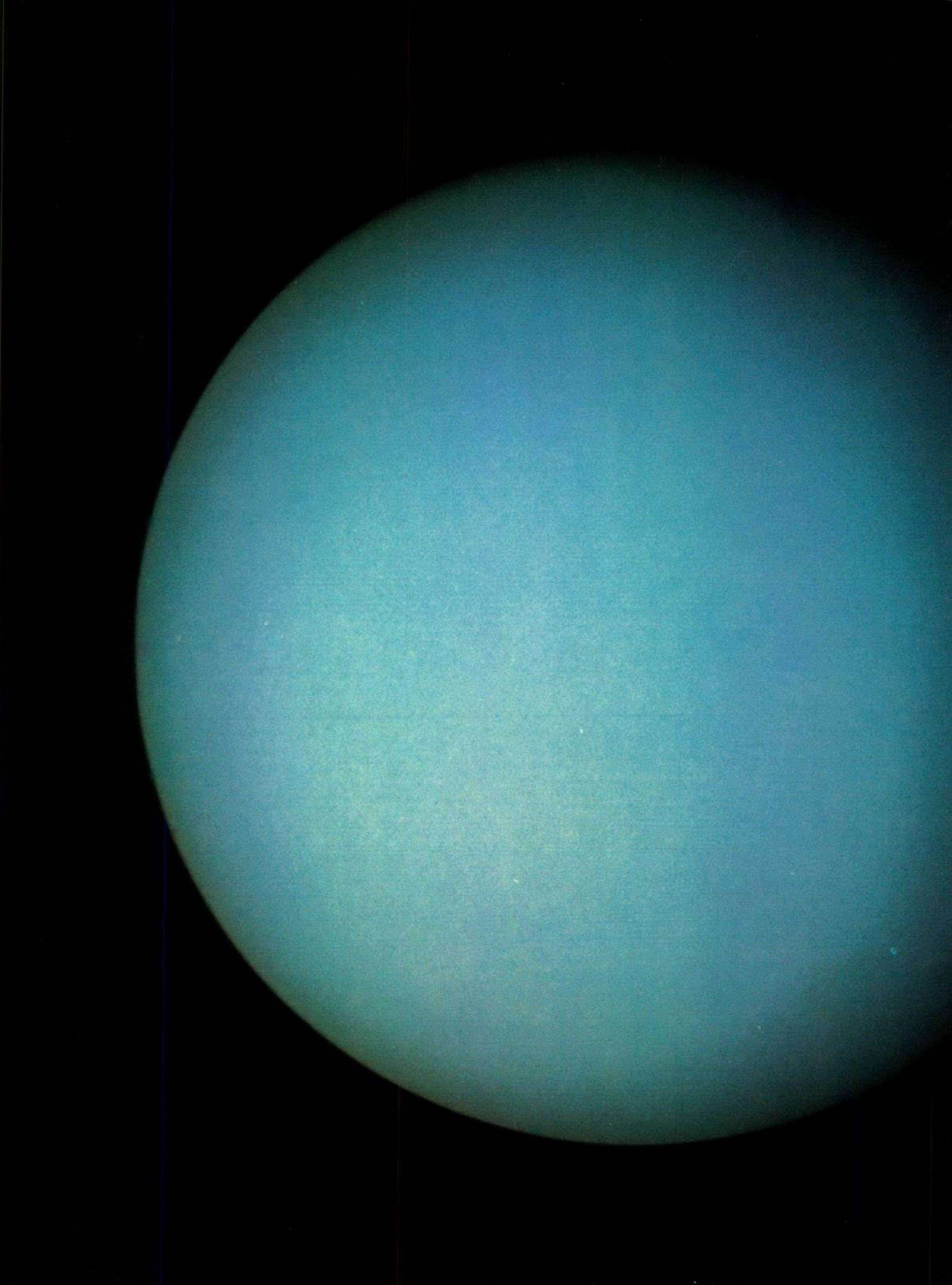


URANUS

THE VOYAGE CONTINUES

By Richard Berry

Aquamarine Uranus is a far more interesting planet than we thought.

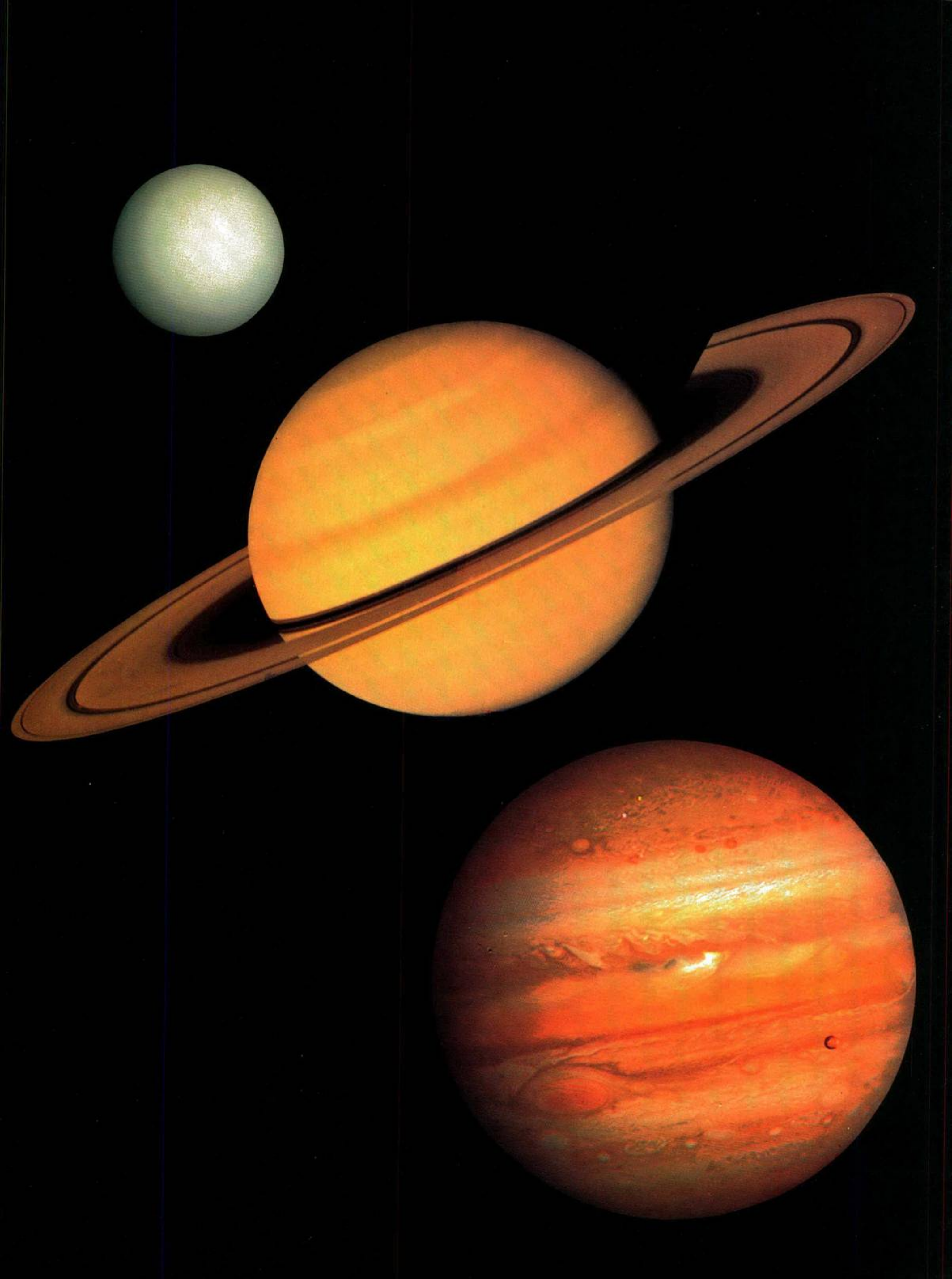
Eight years from home. Three billion kilometers out. Enveloped in the cold of deep space, Voyager 2 is gathering speed as it falls toward Uranus.

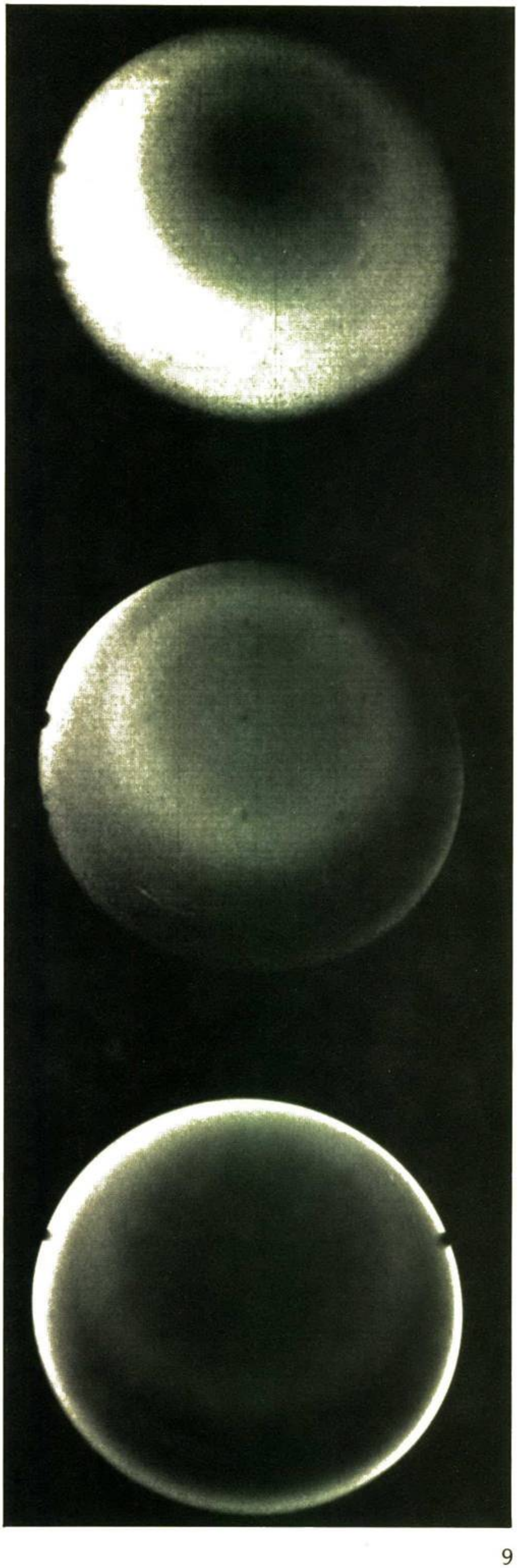
The spacecraft sees the planet's southern hemisphere in its narrow-angle camera. A bland green ball shining in the faint sunlight, Uranus is circled by nine dark, brownish rings. The fully illuminated sphere reveals little more than a brownish yellow polar hood and pale, greenish blue cloud bands rotating with the planet at middle and low latitudes.

> ***"We have now detected clouds in the Uranus atmosphere."***
>
> — *Brad Smith*

January 22: On Earth, the Voyager scientists are pleased with the progress of the mission. Because so little is known about Uranus, Voyager has presented them with great opportunities for discovery. The cameras have recorded nine new satellites circling inside the orbit of Miranda. The cameras have revealed the rings that have never been clearly seen before.

On December 31, Voyager scientists had found a new moon. Named 1985U1, it orbits much closer to Uranus than the five other known moons. With a diameter of only 75 kilometers, it is about one-quarter the size of the smallest moon, Miranda. Six new moons, dubbed 1986U1





Viewed through (top to bottom) violet, orange, and methane absorption band filters by Voyager's cameras, the planet Uranus displays large-scale atmospheric features. The violet image shows haze over the pole, material that is dark in the violet. The orange image (middle) shows a ring around the pole that is probably due to material raised high in the atmosphere by convection. A cloud is visible at low latitiude. In the light of the methane band, the atmosphere is deep and therefore dark. Haze brightens the limb.

through 1986U6, orbit between satellite 1985U1 and the Uranian ring system. All are between 30 and 50 kilometers in diameter.

Then on January 21, they found two tiny "shepherd" moons. Measuring only 15 kilometers across, one on either side of Uranus's epsilon ring, the broadest and brightest of the nine known rings. Eight thinner, narrow, fainter rings lie between it and the planet. The discovery of the two moons orbiting the epsilon ring was a dramatic victory of theoretical predictions. These shepherd satellites corral the tiny particles in the rings into a narrow ring.

The planet itself shows little detail, which is not really a surprise. The ammonia clouds that occur high in the Jovian atmosphere lie lower in the Saturnian atmosphere. In the Uranian atmosphere, they apparently lie deeper still, hidden below layers of haze. Images also reveal that the sun-facing south pole of the planet sports a high, ever-so-slight-brown haze. Sunlight falling on the methane in the largely hydrogen-helium atmosphere converts some molecules to acytelene, which in turn probably forms this polar "smog."

As the spacecraft approaches the near encounter phase of its mission, "computer-stretched" images reveal clouds moving around the planet. Those nearest the equator are moving the slowest, taking 17 hours to travel once around the planet; those nearer the pole move faster, taking 15 hours.

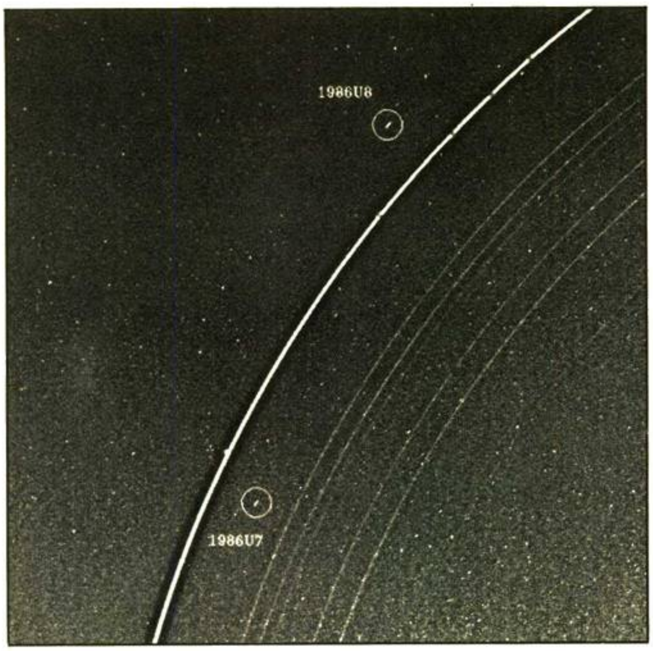
But other questions — many other questions — waited for the brief day of encounter. Did every ring have a shepherd satellite? Would Uranus show a magnetic field? What was the true rotation rate of the bulky planet? What would those first tantalizing details on Miranda, Ariel, Umbriel, Titania, and Oberon reveal? What surprises did this little-known planet hold in store?

> ***"In a few days we'll have answers to questions we're just not smart enough to ask today."***
> — *Ed Stone*

Uranus grows rapidly. Voyager's plasma wave and radio receivers listen to tell-tale radio emissions from the planet; the charged particle detectors respond to the growing particle flux. Riding on the end of its long boom, away from the magnetic fields generated by the one-ton spacecraft, the magnetometers sense changes in the interplanetary magnetic environment.

The infrared instrument scans the looming bulk of the planet, sensing the weak heat radiated by the planet. The photopolarimeter, riding on the scan platform, seeks target after target watching for subtle changes in brightness that, when properly interpreted by the scientists on Earth, will reveal something of the nature of these distant worlds.

Voyager snaps six frames of Uranus, one of Oberon, forty of Uranus, six of the rings, three of Miranda, three of the rings, five of Titania, eight of Uranus. So runs the sequence. Three of Ariel, four of the rings, five of Titania, six of the rings, six of Uranus, four of Titania. The space-



Top: The epsilon ring is flanked by two "shepherd" satellites, 1986U7 and 1986U8. Below: The Uranian rings contain a continuous distribution of small particles ("dust") across the ring plane. This 96-second exposure, taken while Voyager was in the planet's shadow, shows ring dust features invisible from any other viewing angle.

craft computer points the cameras; the image data begins its 2,966,000,000-kilometer journey to Earth — 2 hours 44 minutes 51 seconds at the speed of light.

> *"The spacecraft is in very good health and what difficulties we have had have been worked off."*
> — *Lew Allen*

This image shows all nine of Uranus' previously known rings and a very faint tenth ring called 1986U1R midway between the epsilon and delta rings. The image has been enhanced to bring up these sharp features. Only the epsilon ring — some 100 kilometers wide — is resolved in this image.

January 23: For a week the background radio intensity of the plasma wave and planetary radio experiments had been gradually increasing, but it had gone unnoticed amid the spacecraft noise. Then, on January 19, a strong burst of radio noise at 31 and 56 kiloHertz alerted the scientists to the radio signals. The radio signals were polarized, implying that they had originated from charged particles, electrons presumably, spiralling around magnetic field lines. "A very clear indication," according to project scientist Ed Stone, "that in fact there is a magnetic field at Uranus, and there are spiralling electrons in that magnetic field."

Confirming these radio data are measurements from the charged particle investigation. Fast ions, probably protons, were streaming out from Uranus along the field lines of the solar wind. These may have had their origin at the bow shock, where the solar wind runs into the magnetic field of Uranus.

The detection of the magnetic field was significant: it is one of the ways astronomers have to probe the inside of the planet. The rotation of the magnetic field is tied to the rotation of the core of the planet; in this way, the Voyager scientists hoped to find the true rotation of Uranus.

For the engineers controlling the mission there were only a few minor worries. From images shot as Voyager approached Uranus, and from ranging by the Deep Space Network antennas, the paths of the spacecraft and the Uranian system had been refined and improved. A critical last-minute update of Voyager's stored data on the positions of the satellites ensured that the spacecraft's cameras would be positioned to shoot a high resolution mosaic of Miranda as it passed within 43,000 kilometers of the satellite.

> *"Bear in mind that we're using a spacecraft that's not optimum for observing Uranus.'*
> — *Gary Hunt*

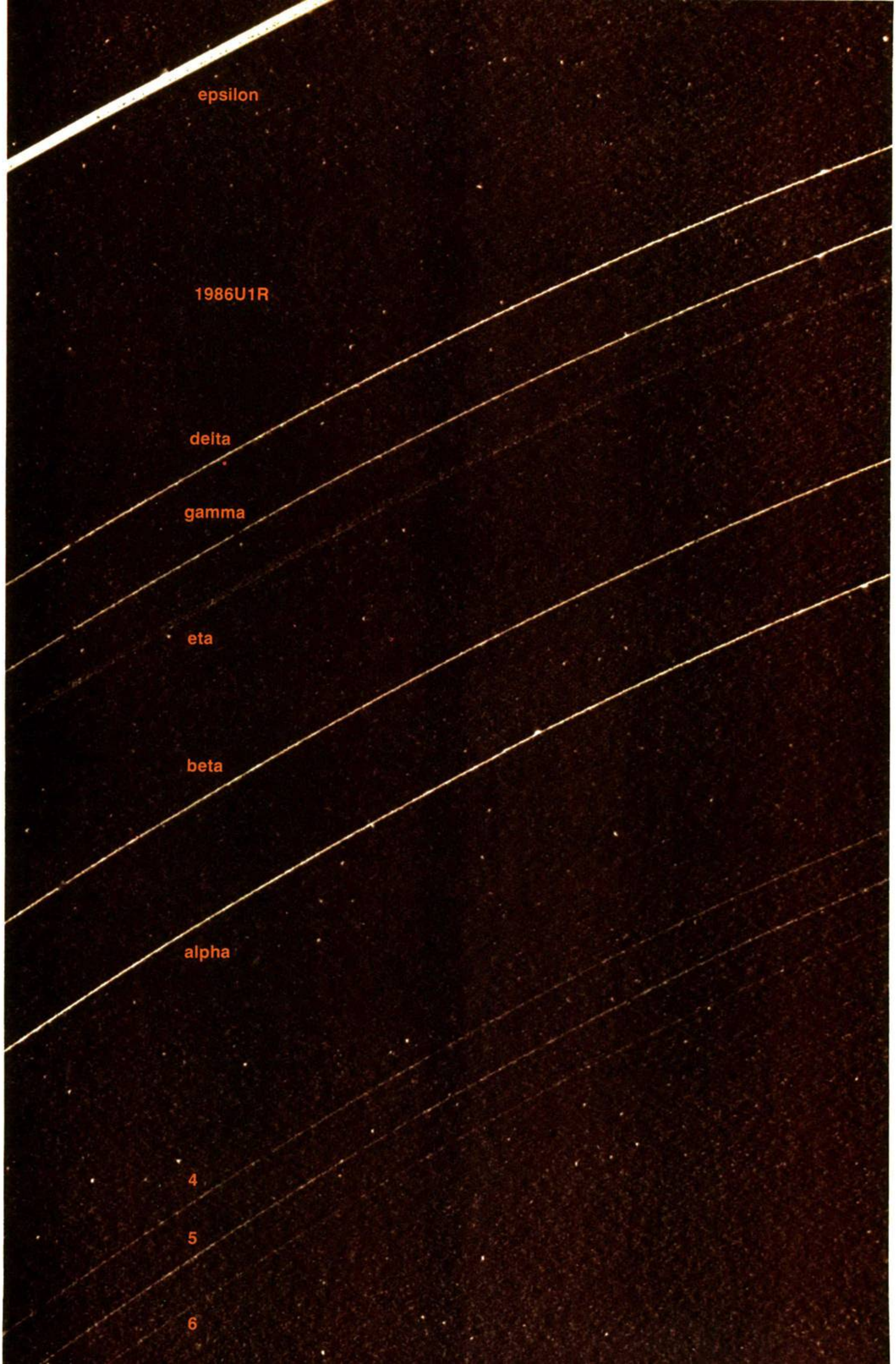
Uranus looms ahead now, soft green in the weak sunlight. The satellites show visible disks; ten thread-thin rings encircle the planet.

In the spacecraft sky, the star σ Sagitarii moves toward the rings. The scan platform slews to acquire it, then locks onto the star. For four hours the photopolarimeter watches as the star cuts a shallow chord across the epsilon and delta rings, flickering as ring material blocks its light.

Voyager then rolls to a new lock star and takes four pictures of Oberon followed by four pictures of Titania; the images are stored on tape. The photopolarimeter reads the optical signatures of the satellites. Two pictures of Umbriel are taken. Infrared, plasma wave, and ultraviolet observations are conducted. A lot happens very quickly as Voyager speeds toward the planet. Two more photos of Titania. Five of Miranda. Four of Miranda.

Voyager crosses the ring plane.

The Sun slides behind the epsilon ring. The radio link experiment probes the ring material with 3.6 centimeter and 13 centimeter radio waves. The Sun slides behind Uranus; eleven minutes later so does Earth. Voyager is in darkness. The spacecraft executes a complex maneuver, smoothly pointing its antenna so that its radio signals will pass deep through the Uranian atmosphere and continue toward Earth.



epsilon
1986U1R
delta
gamma
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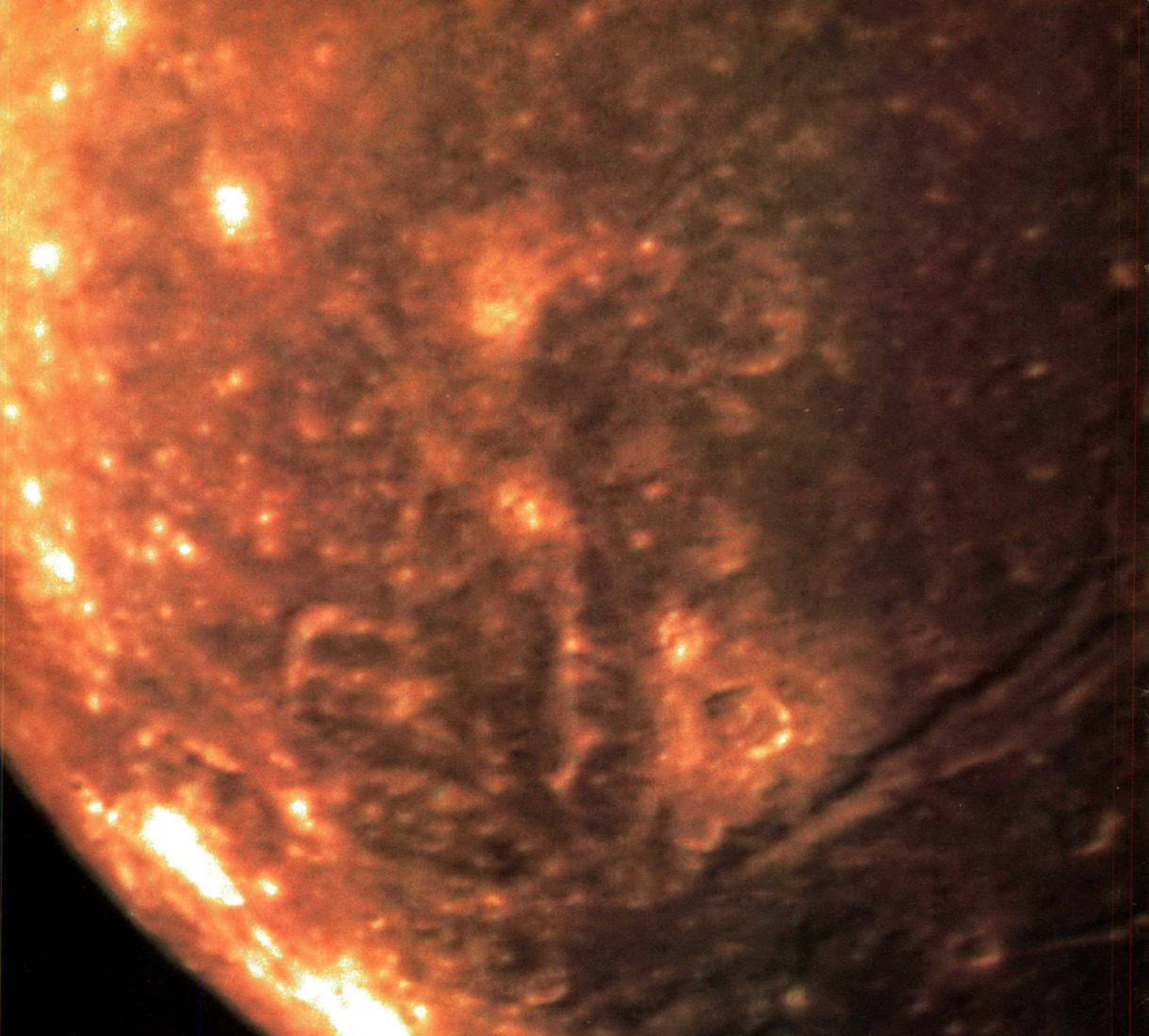
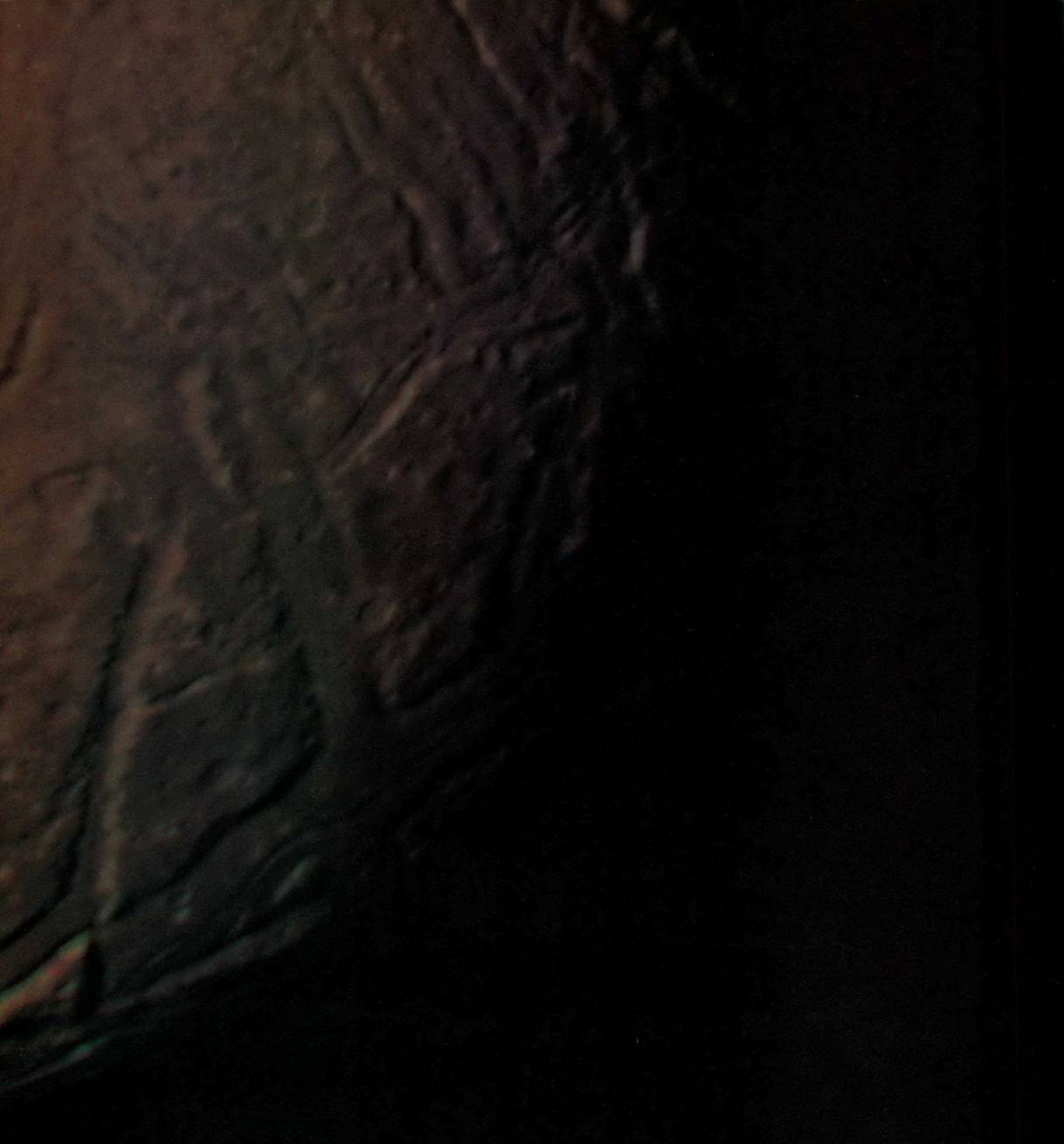
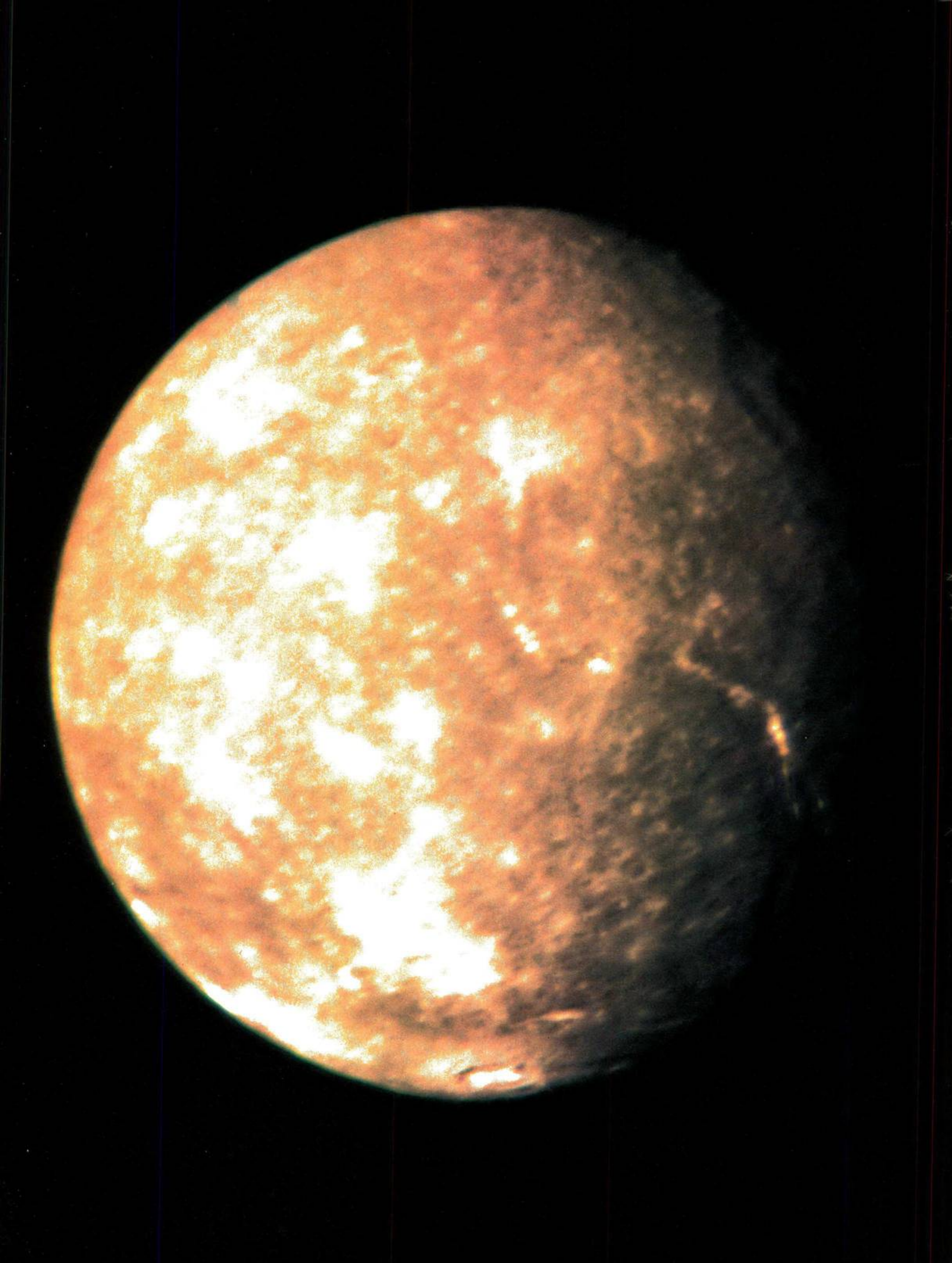
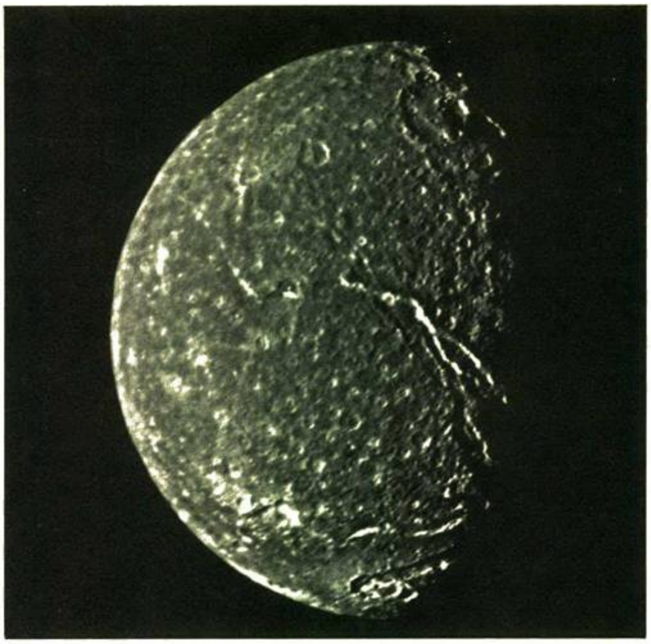
4
5
6





This, the best Voyager image of Ariel, shows the 1,200-kilometer-diameter satellite with a resolution of about 3 kilometers. The surface is heavily cratered and cut by fault scarps and grabens. The bright spots to the left are ray craters. Ariel is the brightest of the Uranian moons, and has undergone intense tectonic activity during its past.





Bright ray craters sprawl across the sunlit side of 1,600-kilometer-diameter Titania. This satellite shows signs of mild internal activity, particularly the large trench near the terminator. The basin at top attests to major impacts in the past. This picture resolves details as small as 9 kilometers across.

This image of Titania has been high pass filtered for maximum image detail.

The camera shutters a series of pictures of the backlit rings — mostly short exposure — and a single 96-second exposure just in case the predictions are wrong and the rings are dim in backlighting.

The Sun blinks into view again. Thirteen minutes later Earth comes from behind Uranus. Looking back at Uranus, Voyager continues observations of the plasma, magnetic, and radio environment and begins observing Uranus's dark side in infrared and ultraviolet radiation and taking pictures of the receding crescent of the planet.

> ***"For the past few hours we have been making direct observations of the magnetic field of Uranus."***
>
> *— Norm Ness*

January 24: Voyager has sent back exciting evidence for the existence of a Uranian magnetic field. Ten hours thirty minutes before closest approach, Voyager crossed the bow shock; three hours later it entered the magnetic realm of Uranus. The bow shock is where the solar wind first encounters the magnetic field of a planet; the magnetopause is the transition from primarily solar to primarily planetary material. The distance at which Voyager had entered the magnetic field gave scientists a preliminary measure of the strength of the field — approximately 0.1 gauss, or three times stronger than Earth's magnetic field.

Meanwhile, the best images of the atmosphere of Uranus were being transmitted. Voyager's cameras were equipped with a special filter centered at a wavelength absorbed by methane. Imaged through such a filter, a clear, deep, methane atmosphere would look dark because the light at that wavelength entering the atmosphere would be absorbed. However, if there were clouds in the atmosphere, the light would be reflected back out before it was absorbed completely. Viewed this way, clouds would appear white.

Pictures already taken this way showed several broad cloud bands, so the astronomers were hopeful that the pictures coming in would show the cloud detail they would need to map the winds of Uranus.

Also looking good were images of the rings. The epsilon ring appeared split into two components. The eta ring looked broader and more diffuse than the other rings. Furthermore, images taken with different filters showed that the gamma and eta rings were differently colored than the epsilon, delta, beta, and alpha rings.

New images of the satellites were showing more and more detail. Titania and Oberon especially showed detail, but the next day's pictures would be better. A strange V-shaped feature could be seen on Miranda, though in too little detail to identify. If all went well, Voyager would soon acquire sharp closeups of the tiny satellite.

> ***"I for one did not expect this degree of activity in the Uranian satellites."***
>
> *— Larry Soderblom*

Monitor magnetic fields, listen to planetary radio signals, search for aurora on the dark side of the hulking planet now sunward, follow the program stored in memory. Shoot frame after hopeful frame in search of the slender rings circling the planet.

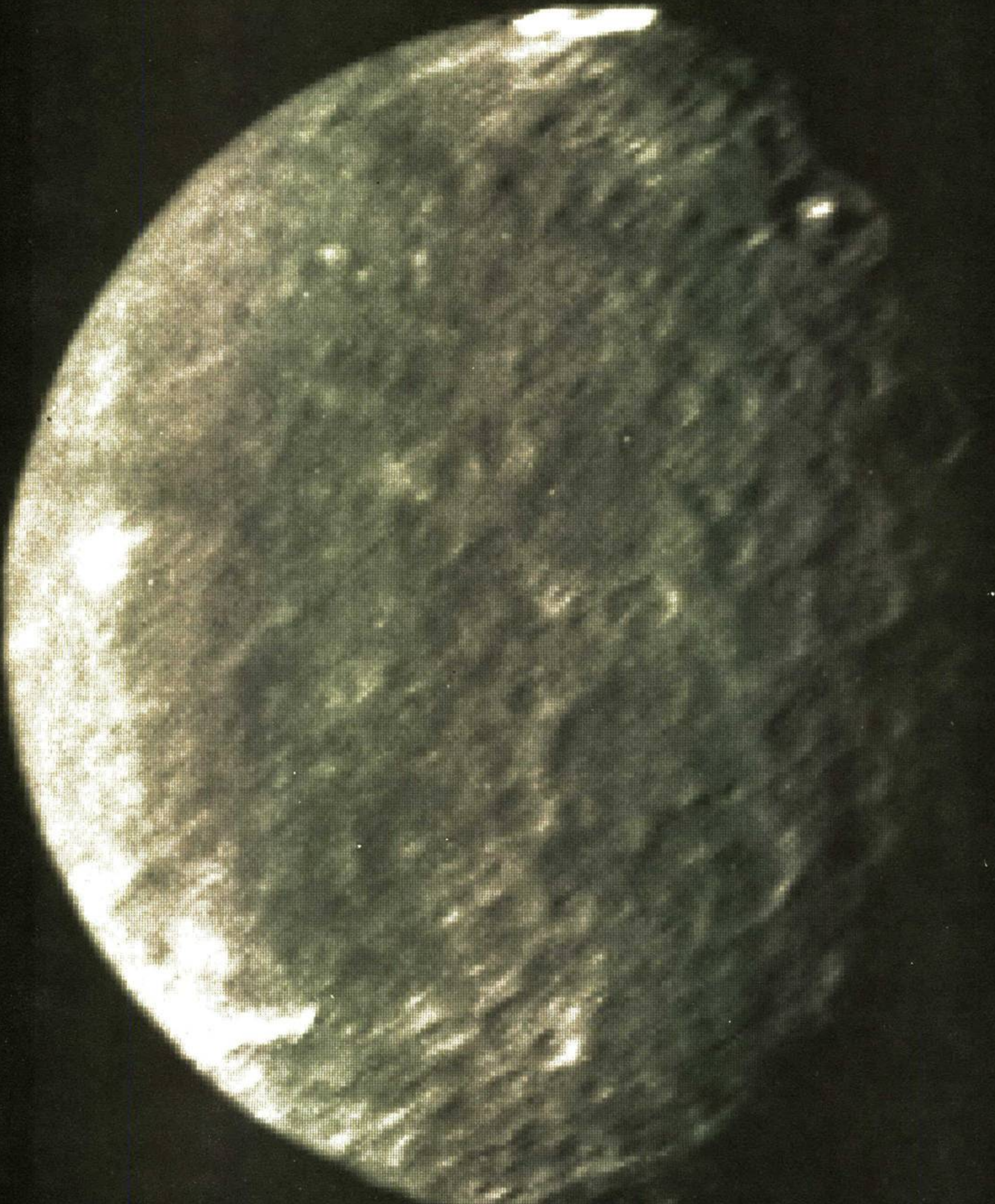
Crescent Uranus gleams in the light of a distant Sun, ringless, a pale yellow-green. Six tiny crescent-lit satellites are spread around it. The rings are invisible. Playback one image of Ariel. Playback four of Miranda. Playback five pictures of Ariel. Playback four of the rings. Seven of Uranus, two of Umbriel, two of Titania, four of Ariel.

> ***"We have to average a couple hundred spectra to get good infrared data."***
>
> *— Rudy Hanel*

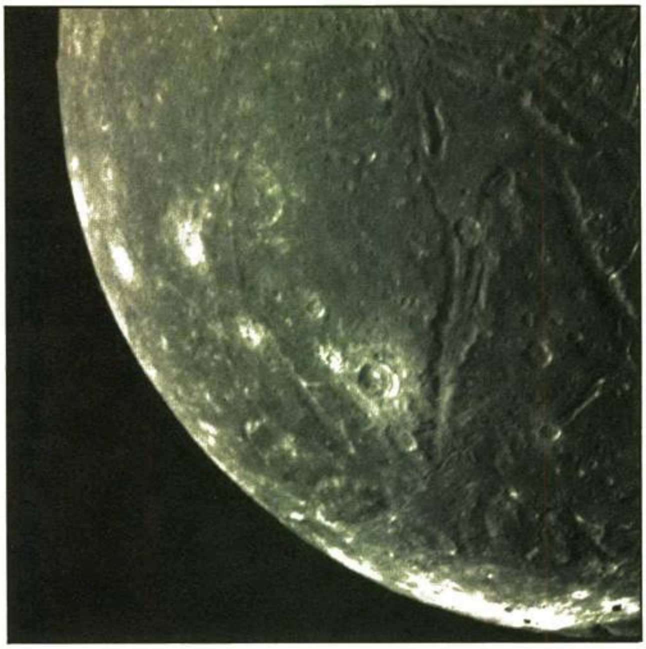
January 25: Overnight the scientists had been busy with the data received the day before. The infrared experiment had taken five hours of data to produce a spectrum giving the first unambiguous measurement of the hydrogen-to-helium ratio in Uranus' atmosphere — somewhere between 10 and 15 percent of the total number of atoms. Although this finding contradicted certain ground-based data that had predicted up to 40 percent helium, the infrared figure was more consistent with the other solar system bodies: 14 percent for the Sun, 10 percent for Jupiter, and roughly 5 percent for Saturn.

Meanwhile, the perplexing magnetic field data was finally making sense. Uranus' magnetic field was tilted an incredible 55 degrees to its rotational axis with its north magnetic pole facing the Sun. The total field was about 10 percent that of Saturn's and .4 percent that of Jupiter.

The ultraviolet spectrometer had completed its scans of the polar region. The data showed an "electroglow" phenomenon rather than the aurora that some scientists had expected. The electroglow is generated when "soft" electrons collide with the gases high in a planetary atmosphere. A glowing hydrogen corona above the pole was also detected. The energy source for these glows could not be sunlight — Uranus radiates 15 times more energy



Left: Umbriel's southern face is heavily cratered but lacks the numerous bright ray craters seen on the other Uranian satellites. Umbriel's dark surface — which reflects about 16% of the light that strikes its surface — distinguishes it from the other large satellites. The 140-kilometer-diameter white ring (at the top of the picture) is about 40% reflective and not understood. Right: Compare these faults on Ariel, signs of geological activity, with the far less active surface of Umbriel on the facing page.



in ultraviolet than it receives in sunlight.

Images inspected the day before showed a new satellite (1986U9, 50 kilometers in diameter) and a new ring (1986U1R). The new ring, so faint that it was barely visible in highly processed images, lies between the epsilon and delta rings.

Images of Umbriel presented a problem: this dark moon appeared virtually featureless except for a bright donut-shaped patch near the terminator. Titania, on the other hand was plastered with craters and crisscrossed with cracks. Bright ridges seemed to suggest something white — frost, maybe — leaking out of the fractures.

The best Oberon images revealed cratering, a six-kilometer-high mountain on the limb, and a large crater with a partially dark floor. Had dark "volcanic" fluids — in all likelihood water on this distant world — been extruded from the interior?

As the day progressed, the recorded high-resolution images of Ariel and Miranda came in. Ariel, with its systems of faults and grabens, excited the geologists greatly. One giant crack stretched a significant fraction of the way around the satellite. Crisscrossing grooves suggested a body broken up, cracked by cycles of heating and melting. There were few craters, objects that would have impacted after the formation of the dramatic geology.

The pictures of Miranda taken a day and a half earlier arrived perfectly pointed and tracked. They revealed this small moon's rugged topography most dramatically. The surface showed a myriad of swirling patterns intersecting and transectioning each other, pocked with tiny craters and inexplicable white streaks and splotches. Its limb was jagged, its terrain grooved, its cliffs and cracks towering. The most stunning feature, however, was a feature called "the chevron", a squarish highly-grooved feature with a bright white V-shape at its center.

"The outer planet missions have really changed our way of thinking how solar system bodies develop."

— Hal Masursky

Sunlight strikes the clouds of Uranus. It is reflected, scattered, or absorbed by the atmosphere of the planet. If it is absorbed, it heats the atmosphere, which then reradiates some of that energy as infrared radiation. To find out how much heat Uranus radiates from its deep interior, Voyager must measure total ingoing and outcoming total sunlight, and the total ingoing and outcoming infrared radiation. The planet's internal energy is the residual that can't be accounted for on the energy balance sheet. Voyager's photopolarimeter and infrared instruments observe the sunlight reflecting from, and the heat energy radiating from, the receding crescent.

The cameras search for lightning in the clouds and aurora over the dark pole. The tape recorder plays back stored images, stored radio data, stored plasma wave data. Voyager sails on.

"The faint broad cloud bands are indicative of large scale circulation of the atmosphere."

— Verne Suomi

January 26: As the data from the closest encounters with Uranus, Miranda, Ariel, Titania, and Oberon came back to Earth, the engineering and science teams felt elated: almost everything had worked perfectly. Even the glitches — the possible loss of an image of 1985U1 — could be rectified, or in this case, replayed.

Cloud images taken before encounter were, with proper processing, showing broad cloud bands in the atmosphere, similar to features seen in the atmospheres of Jupiter and Saturn. A wide bright ring around the pole, imaged through the methane filter, indicated a region of aerosol or haze particles upwelling from below. The polar region, though, was very dark where air was sinking.

More dramatic, though, were new pictures of strong plume features resulting from violent convection from below. Rising high into the stratospheric winds and moving faster than the direction of rotation, one such plume had spread 4,000 kilometers from its origin.

Titania showed complex graben-like structures across its surface. Ariel showed faults and valleys intersecting, and other flat-bottomed valleys with slender sinuous rilles running down their floors. Craters on the valley floors suggested that the valleys might be old, or at least not young.

Miranda, however, stole the show. The variety of terrains on this barely 300-mile-wide moon stunned the Voyager imaging team. Voyager's aim and tracking had been nearly perfect. Each image revealed a new and different group of features. One showed a dark terrain that appeared to be layered — like so many giant crepes — rimmed by a high range of mountains. Another showed a deep trench — kilometers deep — between two terrains, with scarpes and terraces running parallel. Yet another recorded rope-like ridges side by side with another geological province of straight, parallel ridges.

The chevron-shaped feature, now seen at better than one-kilometer resolution, showed closely spaced parallel

Voyager's first new satellite, 1985U1, seen closeup. Its dark surface is only one-third the size of Miranda. The command sequence to image 1985U1 was programmed into Voyager very late in the process. The image was lost at the time of its reception due to a failure of the Australian 64-meter antenna but sucessfully retransmitted a few days later.

ridges, transitions from dark to light topography, with a sharp line of demarcation between them and oddly truncated impact craters with short ray features. The same frame showed what the geologists called "lobate sublinear structures" that look as if the ground has been compressed.

The ultraviolet spectrometer had done its work well. The spectra of γ Pegasi, recorded when Uranus occulted it and again as it emerged from behind the planet, traced a thin atmosphere of nearly pure hydrogen gas 4,000 kilometers above the surface and measured its temperature as 750 Kelvin above the sunward pole and 1000 K above the northern pole.

Enveloping Uranus is an even vaster cloud of protons, ions, and electrons, a radiation cloud more intense than that surrounding Saturn. As it sliced through circum-Uranian space, Voyager's sensors measured the plasma temperature as 400 million degrees Kelvin. Thought too low in density to heat anything, this sea of energetic particles is capable of blackening exposed methane ice on the surfaces of the satellites.

At high particle energies, Voyager's cosmic ray detectors helped pin down the tilt and configuration of the magnetic field. Because the satellites absorb high energy particles, dips in the particle intensity show where the magnetic field lines go. From the particle intensity readings, Miranda is particularly important in capturing the particles greater than a million electron volts, scraping away at the edge of the Uranian radiation belt.

The enormous collection of data returned from the stellar occultations tracked by the photopolarimeter were just beginning to be studied. From the σ Sagitarii occultation, the epsilon and delta rings showed complex structure. The epsilon ring structure appeared random and was certainly different in the two regions that occulted the star. The delta ring was more regular; even the small features in it seemed to line up fairly well. The gamma ring, which imaging had suggested would appear narrow, was only 600 meters wide. The newest ring, 1986U1R, turned out to be some three kilometers wide.

Right: Miranda, the smallest of Uranus' five major satellites, is also the most geologically active. At a resolution of 2.7 kilometers, this body shows distinctive dark regions with parallel banding as well as presumably older cratered terrain. At left is part of the light-colored "chevron" structure.

In addition to the nine known rings and the new tenth ring, at least ten new, exceedingly narrow ring arcs — partial rings like those anticipated at Neptune — were revealed in a small portion of the photopolarimeter data.

Plasma wave data recorded at the time of ring plane crossing had detected dust particles at the ring plane, approximately 30 "hits" per second. At a relative speed of 20 kilometers per second, the impact of a dust particle a millionth of a meter in diameter produces a burst of radio energy on the sensitive radio receiver. When Voyager crossed the Saturn ring plane much closer to the rings, it had recorded some 600 dust impacts per second.

Finally, late in the day, two important image sequences came back to Earth. First were a series of long exposure images of the backlighted rings taken while Voyager was still in the shadow of Uranus two days earlier. Amazingly, one image — the 96-second exposure — showed the softly shining fine dust that the Uranian rings seemed to be lacking at ordinary backlighting angles — shining so strongly that the ten narrow rings could not at first be located within the glowing ring of dust.

> ***"What do we learn about the Earth by studying the planets? Humility!"***
>
> — *Andy Ingersoll*

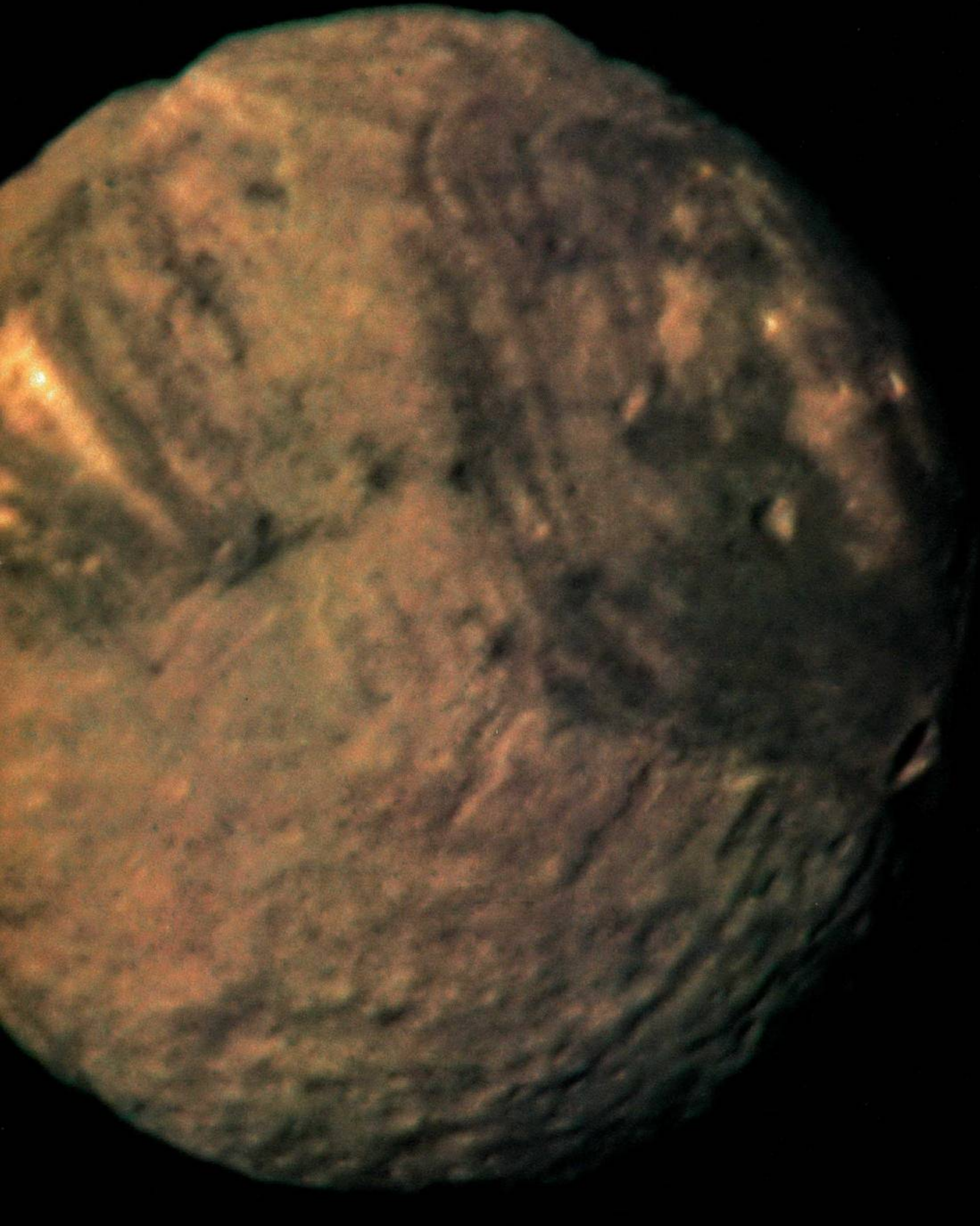
Uranus now shines as a slender crescent sunward of Voyager. Six tiny crescent moons orbit it. The broad gossamer band of dust and the narrow threads of larger material — all but invisible to Voyager's sensitive camera eye — ring the planet.

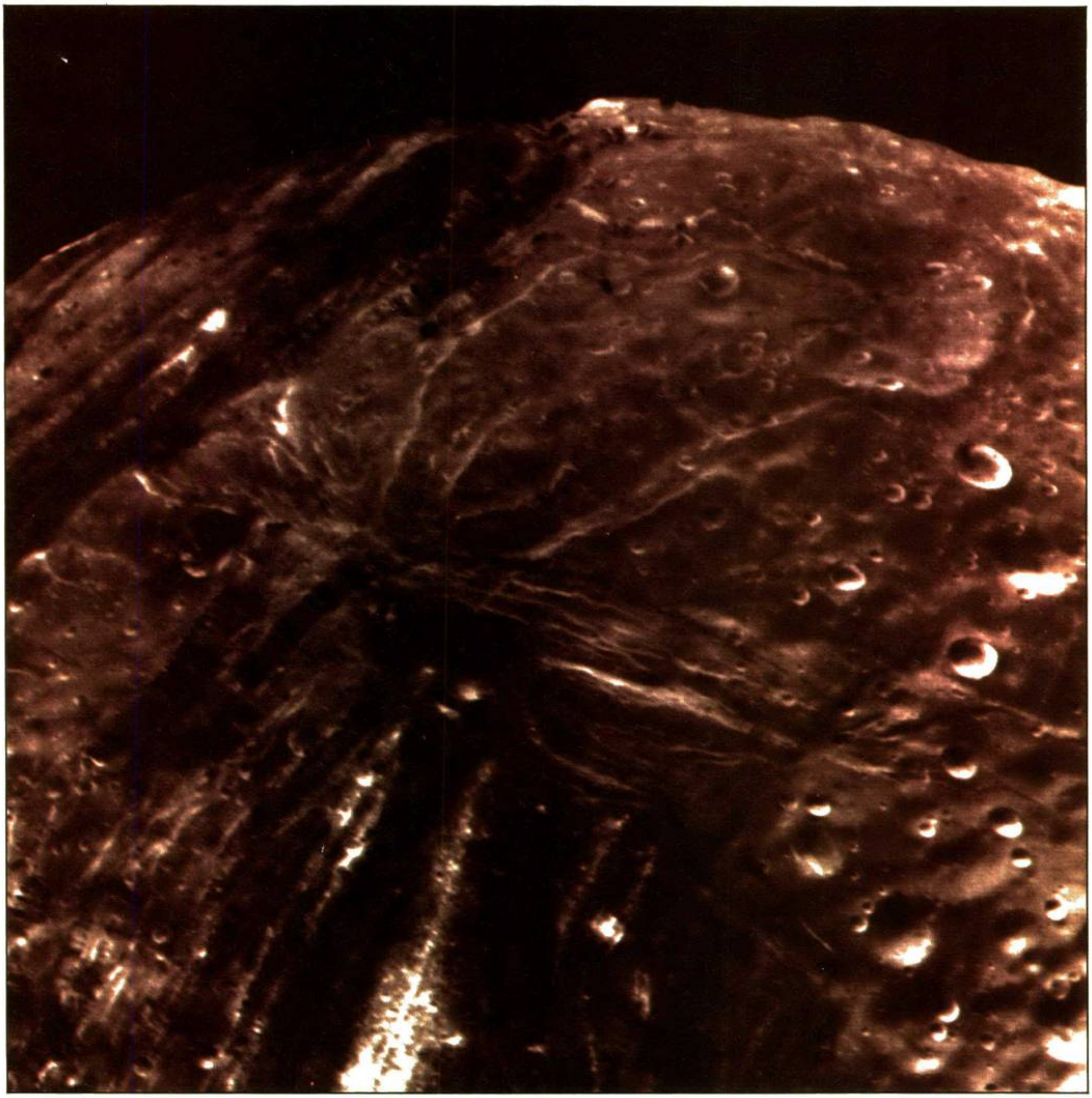
Trapped in the twisting magnetic field lines, an invisible flux of protons and electrons teases the boom-mounted magnetometer. Radio waves beat a tattoo on the long antennas. Infrared radiation washes over the spacecraft; Voyager's sensors eye the fading auroral glow on the dark hemisphere where energetic electrons skid down magnetic field lines and collide with the atoms and molecules of the planet's atmosphere.

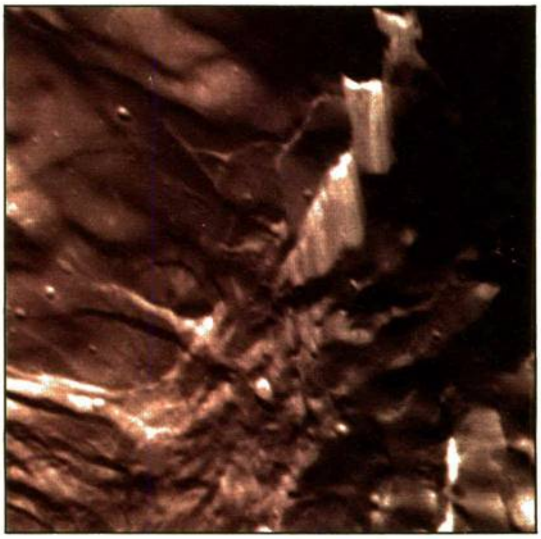
Voyager's tape recorder stores many of these observations: samples of plasma wave signals, the ongoing search for aurora in the ultraviolet, infrared spectra of the atmosphere over the dark side of the planet, and navigation images of the satellites. Much of Voyager's job is now playing back the rich store of taped observations made near closest approach. Two- and three-day-old pictures of the dark side of the planet, taken to search for lightning as well as high resolution images of Ariel and Miranda, are played for the second time. The β Persei and γ Pegasi stellar occultation data recorded by the photopolarimeter once again is beamed toward Earth.

> ***"The ring occultation data is safely on Earth."***
>
> — *Dick Laeser*

January 27: More data had come back, and, more

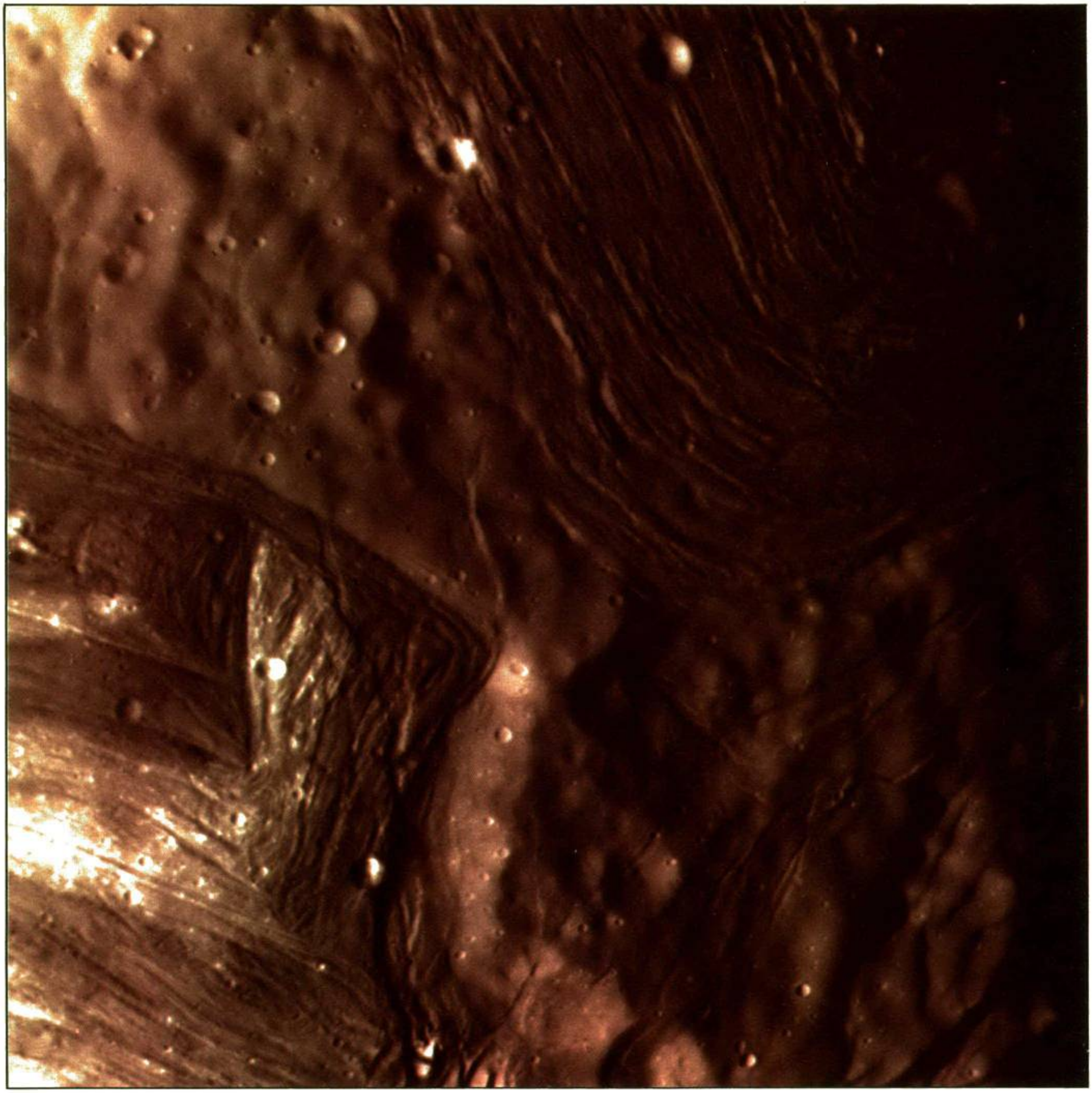


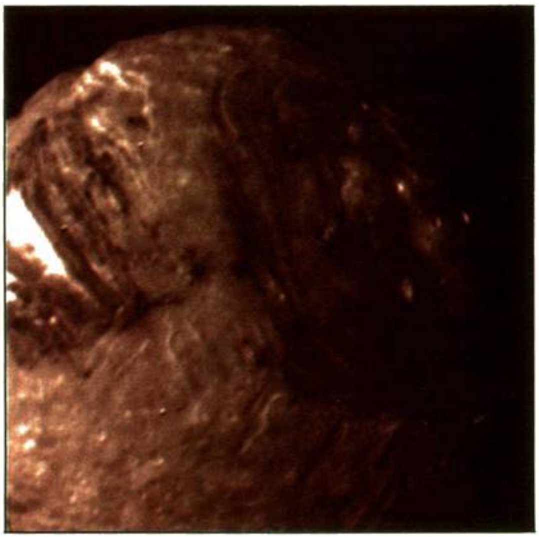


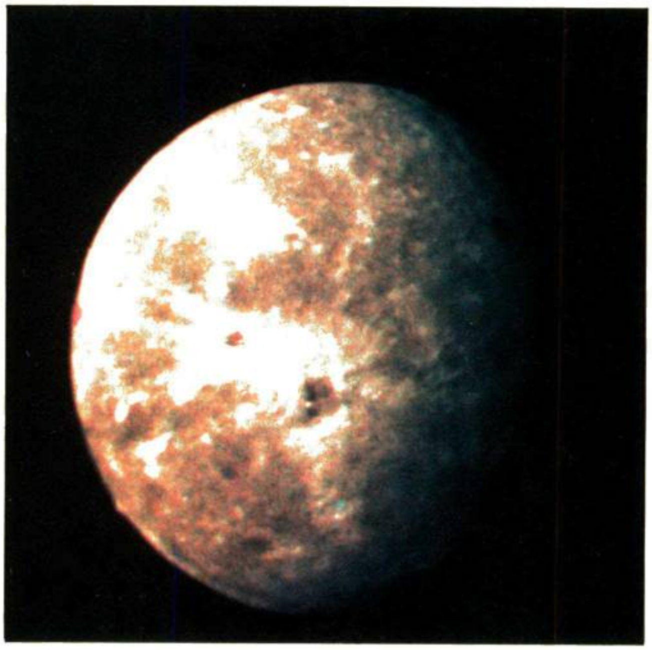


Top left: Where cratered terrain and complex deformed grooved terrain meet, there is a great trough, visible here in a cross-section on the limb of Miranda. The giant scarps and cliffs are several kilometers high and point to a geological activity that was hardly anticipated on this tiny moon. Left: A cliff some 5 kilometers high marks a fault, where internal forces have torn the crust of Miranda. The resolution in this frame is 660 meters, or about 2,000 feet. The terrain on the high side of the fault is thought to originate from compressional forces.

Top right: In high-resolution images, Miranda's "chevron" turns out to be a geologically complex region of grooved terrain. Scarps and faults cut across the grooves. The region shown in this picture is 220 kilometers across. Bottom left: From a distance, Miranda's features are indistinct. Note the mysterious bright "chevron" feature. Bottom right: At this resolution, only two terrain types are visible, old cratered terrain and dark "marbled" terrain. The chevron appears at the right side of this image.







This, the best Voyager image of Oberon, shows a large crater with a dark floor in the center of the disk. The dark floor may be material that flowed from the moon's interior. A mountain 6 kilometers high protrudes from the limb at the lower left. Oberon also displays many conspicuous bright ray craters.

importantly, enough data had finally accumulated to estimate the rotation period of the planet. The difficulties stemmed from radio noise generated by the spacecraft itself and from the problems of deriving a precise period from a short run of noisy data. The planetary radio astronomy experiment had picked up modulations caused by rotation some fifteen days before encounter; these had a mean period of 16.8 hours with an uncertainty of 0.3 hours.

In the weeks that would follow, the astronomers expected to reduce the uncertainty by a factor of ten because the post-closest approach radio signals were ten times stronger than the pre-closest approach signals, which would make picking out the planet-generated signals much easier.

The infrared team also had a chance to examine some of their data. They had atmospheric temperature profiles for both poles and the equator and had measured the distribution of temperature from equator to pole. On the sunlit side, Uranus did indeed have a pole warmer, at 65 Kelvin, than the equator, at 64 Kelvin. This was much smaller than the 5-degree difference the scientists had expected. In addition, Uranus had a cold "collar" between 10 and 40 degrees latitude, where the temperature dropped to 62 Kelvin. The expectedly flat temperature profile of the planet implied that Uranus has dynamic patterns of meteorology that are capable of distributing incoming solar heat around the planet and to the equator.

PHOTO INFORMATION

Page	Object	Range*	Photo Number
Cover	Uranus	1,000,000	P-29539
4-5	Satellites	various	P-29464
6-7	Uranus	9,100,000	P-29478
8	Rings	4,100,000	P-29466
9	Uranus	2,100,000	P-29517
10 (top)	Ring Shepherds	4,100,000	P-29466
10 (bottom)	Dust Rings	236,000	P-29525
11	Rings	1,120,000	P-29507
12-13	Ariel	170,000	P-29523
14	Titania	500,000	P-29509
15	Titania	369,000	P-29522
16	Umbriel	557,000	P-29521
17	Ariel	130,000	P-29511
18	1985U1	500,000	P-29519
19	Miranda	147,000	P-29524
20 (top)	Miranda	31,000	P-29513
20 (bottom)	Miranda	36,250	P-29542
21 (top)	Miranda	42,000	P-29515
21 (bottom left)	Miranda	1,380,000	P-29505
21 (bottom right)	Miranda	150,000	P-29510
22	Oberon	660,000	P-29501

All photographs courtesy of the Jet Propulsion Laboratory of the National Aeronautics and Space Administration.

*Ranges are given in kilometers. To convert to miles, divide by 1.6.

Meanwhile, the meteorologists had been hard at work. Using rotation rates for clouds at three latitudes and the new planetary rotation rate, they found "prograde" winds — winds in the direction of rotation — for all three latitudes. This created a problem: prograde winds normally imply that the temperature decreases toward the pole, the reverse of the temperature gradient that the infrared team had actually measured.

The ultraviolet spectrometer had picked up the spectrum of aurora on the dark side of the planet. Generated by high energy electrons colliding with atoms high in the atmosphere, the detection of aurora were no surprise after detection of strong Uranian radiation belts.

The previous days' radio occultation data was also starting to make sense. Beforehand, there had been some doubt whether the rings, if composed mainly of fine dust-size particles, would block the radio signal from Voyager at all. But they showed up clearly in the data, and the first results were quite a surprise. The epsilon ring contains very few particles smaller than one meter across. These radio data fit perfectly with the photopolarimeter data and the pictures that had failed to show the rings brilliantly backlit.

However, even though the rings apparently contained very little fine particles, one image taken for the purpose showed dust. Shot while Voyager was in the shadow of Uranus and tape recorded for later replay, the 96-second exposure revealed a broad glowing ring of fine dust shining against a background of stars. Though filled with features, the new ring image defied quick analysis. Of the known rings, only the epsilon ring could be identified with any certainty.

Lastly, the imaging team scientists examined the image of 1985U1 that had nearly been lost. The tiny moon, barely 160 by 170 kilometers, turned out to be a scant 4 percent reflective. The image clearly showed one large crater on it.

> ***"We can't as easily return to Uranus as we can to Jupiter and Saturn. Some of the pictures that come in today are the best we'll have for a very long time."***
>
> *— Carl Sagan*

Voyager will continue its examination of Uranus, imaging the receding crescent, listening to the radio signals coming from the dark side of the planet, scanning the dark side of the planet for infrared heat radiation and ultraviolet emission, until Uranus is far behind.

Now on its way to Neptune, Voyager will arrive there in August 1989.

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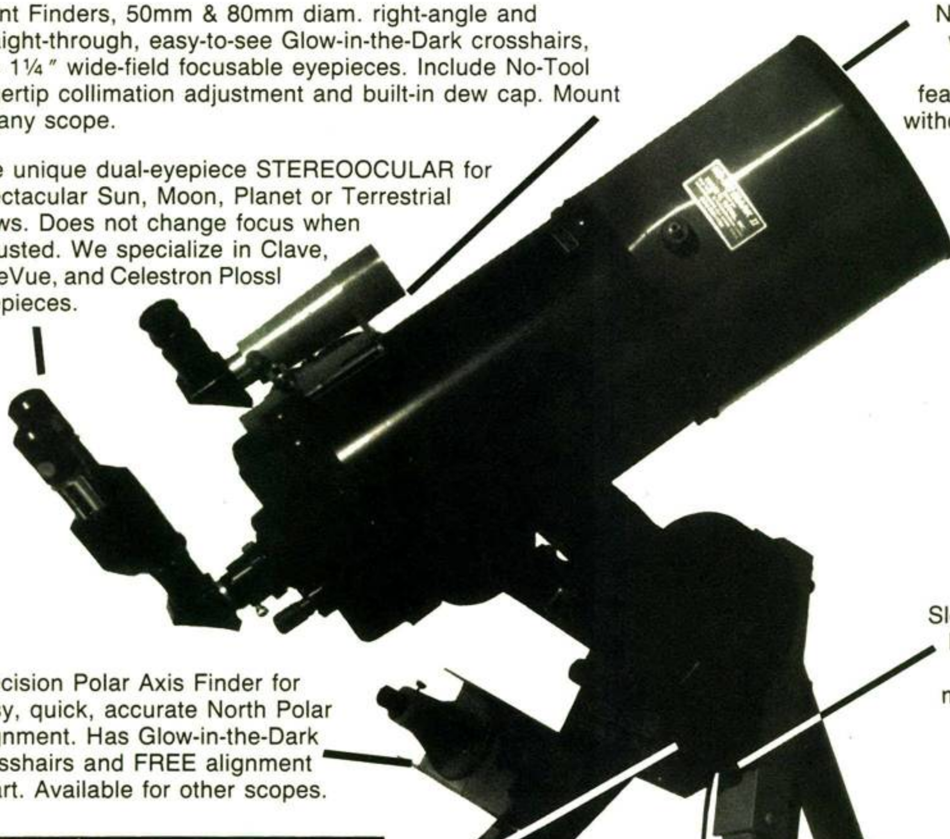

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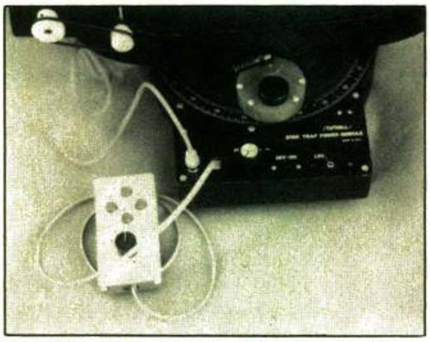

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Francis R. Scobee, Commander
Cmdr. Michael J. Smith, Pilot
Dr. Judith A. Resnik, Mission Specialist
Ronald E. McNair, Mission Specialist
Lieut. Col. Ellison S. Onizuka, Mission Specialist
Gregory B. Jarvis, Payload Specialist
Sharon Christa Corrigan McAuliffe, Teacher Observer

Planetary Astronomers Meet in Baltimore

On October 29, 1985, the Division of Planetary Sciences (DPS) of the American Astronomical Society convened in Baltimore for four days of scientific papers, meetings, and of course the all-important informal contact that makes modern science work. It was an exciting meeting abuzz with the current apparition of Comet Halley and the imminent Voyager 2 flyby of Uranus.

Like a dark cloud hanging over the gathering, though, was concern over NASA's failure to place the long-planned Comet Rendezvous and Asteroid Flyby (CRAF) mission in its fiscal 1987 budget. This move could signal either postponement or outright cancellation of the mission. The news was all the more distressing because CRAF was the first of the new, low-cost missions recommended by the Solar System Exploration Committee (SSEC) of the NASA Advisory Council.

Weighing heavily on the minds of many astronomers was the larger issue of how to interpret NASA's cancellation or postponement of a flagship mission. Was it simply a sign that funds were tight or did it imply that NASA no longer supported or had deprioritized planetary exploration?

The first morning of the meeting was devoted to the year's hot topic — comets. After welcoming remarks by representatives of Johns Hopkins University and the Space Telescope Science Institute, the meeting began with comet papers. Leading the lot was an invited talk on ICE's flyby of Comet Giacobini-Zinner (G-Z) by Tycho von Rosenvinge and John C. Brandt. These two ICE mission astronomers outlined the mission's preliminary results with slides showing the intensities of the fields and particles encountered in the fly-through. (For a report on this mission, see "ICE: Mission to Comet Giacobini-Zinner," ASTRONOMY, December 1985.)

Doug Brownlee then gave a fascinating account of cometary dust, which, it turns out, we routinely collect here on Earth. That's right: there's comet dust in your backyard. The dust particles are so small and fluffy that they don't burn up when they strike the top of the atmosphere but instead melt into tiny spheres that slowly sink to the ground. The smallest particles of dust don't even melt but arrive intact.

Comet dust is gathered from "clean" places like the ice in Greenland, the ocean floor, and high in the stratosphere. As Brownlee put it, "The round stuff is extraterrestrial, and you can prove it." Based on studies of isotope ratios, one sphere studied had been exposed to galactic cosmic rays for at least a million years, confirming its cometary origin.

Under an electron microscope, Brownlee studies the single mineral grains, chips of carbonaceous material, and "tarballs" that make up comet dust. Tarballs are aggregates of exceedingly fine crystals, ribbons, and whiskers of the mineral enstatite. Brownlee's slides of highly magnified views of comet dust showed the crystalline structure of the mineral components. High deuterium to hydrogen ratios mimic the composition of the interstellar medium, suggesting a "pre-solar component" in the material.

After we broke for coffee and Danish, the meeting divided into two sessions, one on comets and the other on Jovian satellites. Ordinarily I would have opted for the satellites, but with Halley coming I wanted to hear the latest. Mike Belton led off with an analysis of Halley's light curve. The comet's nucleus appears to be between 4.2 and 5.2 *kilometers in diameter*, Belton reported, and reflects roughly 26 percent of the energy that strikes it. Its density is around 1.7 g/cm^3 and the

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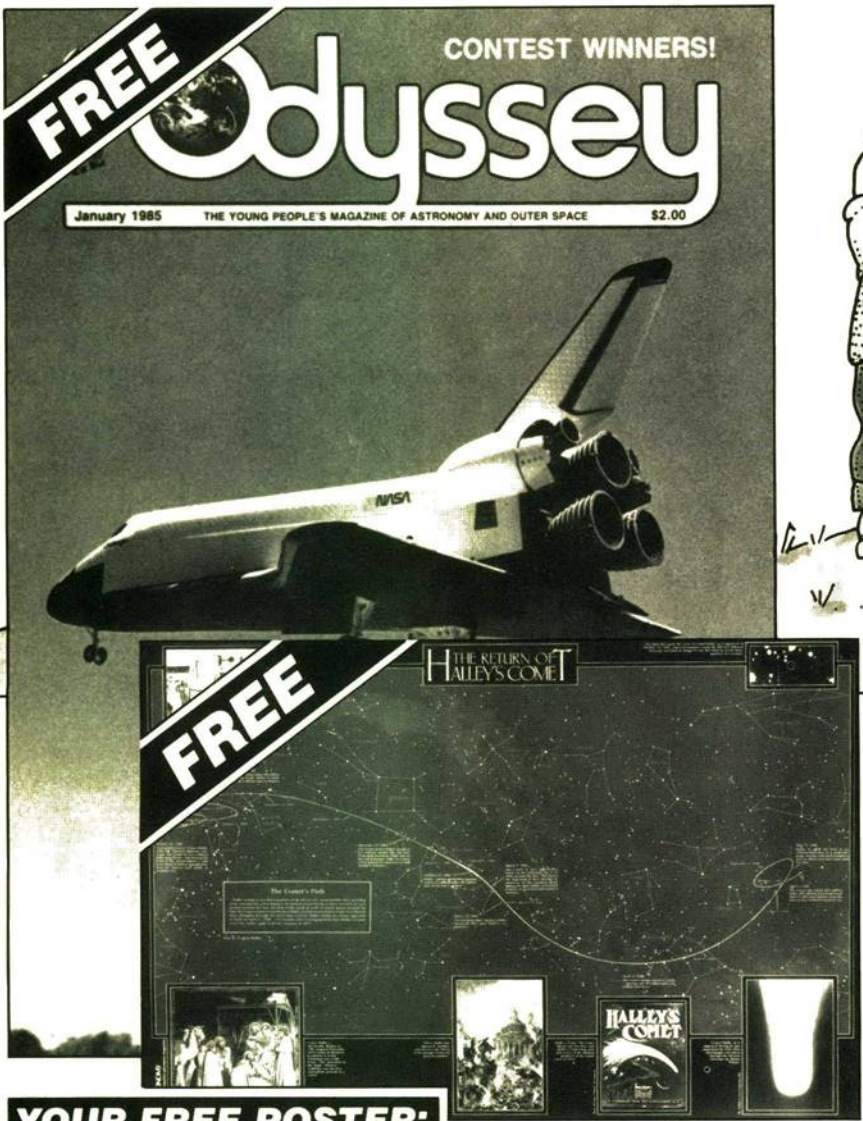
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mass is 7 x 10^{16} grams.

"Coma development began here," said Belton as he pointed to observations made when Halley was 6 astronomical units (AUs) from the Sun. This coincided with a sudden outburst of the comet that, according to Belton, "could be related to exothermic phase changes in amorphous ice." (It seems that when ultra-cold cometary ice warms above a certain temperature, it may give off considerable energy or even explode. This explains certain anomalous cometary behaviors.) "You can see that points beyond 3 AUs are below the Morris and Green curve," he noted, but added that the comet has since brightened. "This appears to be a normal return," he concluded, "one like the 1910 return."

Heidi Hammel presented a series of brightly colored, computer-enhanced CCD images made with the 88-inch University of Hawaii telescope on the summit of Mauna Kea. Her images, taken in August, show a 15-arcsecond coma. One image, shot through a filter passing 7025 Angstrom light from OH^+, showed a jet-like streak 7 arcseconds long curving outward from the nucleus. "It might just be a chance alignment of pixels," she said after the lights were turned up.

Next, Karen Meech reported on photometric studies of Halley. The most interesting finding was that Halley's range of brightness variation, which had been around a magnitude in October 1984, had dropped to half a magnitude by January 1985. Meech attributed this to the growth of the comet's coma, which tends to mask the rotational light variations of the nucleus.

Papers presented in the afternoon tended to be *more theoretical;* they touched on the rotational periods of comet nuclei, how magnetic fields interact with comet's tails, magnetically channeled outflow of gas, and "dust levitation" from comet nuclei.

Late that afternoon, Bob Nelson, the DPS press officer, arranged for the media to talk to Lew Allen, head of the Jet Propulsion Lab. When Allen, a high-ranking Air Force officer, was appointed to this post several years ago to replace Bruce Murray, a civilian scientist, there was considerable concern. Did his appointment mean that JPL would be doing military work?

The concern, at least among NASA scientists, was that if JPL switched from civilian to military work, the exploration of the planets would suffer. JPL has not, however, quietly slipped into Defense Department work.

Lew Allen is a tall, tan, healthy looking man who moves and speaks with confidence. He identified the greatest danger to JPL as the timing of missions rather than competing military work. But the hard fact is that the amount of Department of Energy work has shrunk and Defense Department work has replaced it. Lew Allen has, however, placed stringent requirements on the type of work JPL will do. It must be in the national interest, it must be related to NASA, and it must be suitable for JPL.

"There are people at JPL who would like to pursue purely civilian work," he said, "but in my opinion this has not been a significant problem."

How, then, does mission timing hurt planetary exploration? The science and engineering teams that designed, assembled, and tested Galileo were ready to move on to the CRAF mission, but CRAF won't be there. So the teams will break up. Even if CRAF is in the 1988 budget, the people who know how to build spacecraft will have left JPL for other jobs. The bottom line is that funding by fits and starts doesn't make sense in terms of human talent. "The whole planetary program," Allen said, "is in jeopardy. I am very concerned."

Does the manned space program hurt space science? Does the Space Station starve planetary missions? "The planetary program has not appeared to have captured the imagination [of the public in recent years]." Perhaps, Allen suggested, "we have not done as good a job as we could have done in portraying planetary exploration as exciting and dramatic."

In the evening, the annual open session on public policy convened with a panel consisting of DPS chairman Laurel Wilkening, Congressman Bill Green, JPL's Lew Allen, and NASA Administrator James Beggs. The topic was "Planetary Exploration Through the Year 2000." Intended as an upbeat discussion between the scientists and Beggs, the evening turned into a rather bitter exchange because Beggs cancelled out and his replacement, NASA Associate Administrator Burton Edelson, also failed to appear. In their place, owl-eyed Geoff Rosendahl took the flak for NASA management.

"It is difficult to focus on the future because the present is very immediate," said Wilkening in her opening remarks. "Even NASA seems focused on the present. Still the question remains, where are we going in space?"

Wilkening stated that the general public is primarily interested in space as a place they might themselves go. "Their attitude could be summed up by saying, 'If they can put a senator in space, why can't they put me in space?' Many people expect that in fifty years, they will be able to travel to the Moon or Mars."

"We can't get there from here," Wilkening added. The Shuttle, which was sold to the public as a cheap way into space, "still costs $2,000 per pound to launch into low Earth orbit. The problem is that it's expensive. Too expensive."

Lew Allen critically reviewed current space activities within the context of mission planning. "The SSEC is a very commendable process, but questions now arise from it." Allen contends that the broadened Soviet space program seems to spring from American planning. "The Soviets [appear to have designed their space program] to preempt our missions, and they have made open and aggressive invitations to Europe [to join them in space.] It leaves me feeling," he said, "that they're skimming the cream off our program."

Allen forsees great difficulties for the planetary program, not only with funding in the era of deficit reductions but also with competition from other science programs within NASA. For the near-term, however, Allen believes "*the U.S. should stick to the SSEC* program and start on that planetary series."

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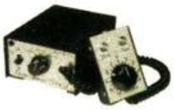

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Geoff Rosendahl presented a NASA/ Office of Space Science Applications point of view. "OSSA is embedded in a larger system," Rosendahl said, "a system that seems to be in transition." Money is tight and there are many ways to spend that money. "Planning processes in other fields currently total two times the available funds," he explained, and many of those programs have long-term financial profiles. The great observatories, like the Hubble Space Telescope, have "a long flat tail in operations costs; in planetary science, Voyager and Galileo are long, long missions." A lot of funds are also used to run old programs rather than start new ones.

"There's a mismatch between scientific and political time scales," Rosendahl reminded the scientists. Political decisions are short term and pragmatic; the scientific work often takes decades. He ended by assuring the DPS that planetary exploration will continue to have a place within NASA.

Bill Green outlined some of the processes that go into budgeting at the federal level and explained why sometimes promises aren't kept. "Let me make it clear at the outset that planetary science is not being picked on," he said. "You are aware of the experience with the Space Shuttle, how it squeezed out an enormous amount of science. There are similar concerns with the Space Station." He added that the Space Station was predicated on an agreement between NASA and the OMB that allowed for one percent real growth in funding. But, Green said, "this was an impossible promise."

After the speakers' initial remarks, the audience asked questions. Dave Morrison queried, "Well, how do we get from here to there?"

Green answered that before you could consider the question of how, you had to know what you wanted to do. "You must determine why you want to be in space and what it is that you want to accomplish. What are the long-run purposes of attaining this goal?"

Rosendahl also responded, emphasizing the value of planning and knowing one's goals, and asking "What does it take to maintain the vitality of a space program?"

Allen countered that with the CRAF postponement, NASA had "made it clear that SSEC was disavowed."

"SSEC has not been disavowed," said Rosendahl. "Other forces came along; we're trying to maintain progress on CRAF. [But the situation is such that] anything we do to help CRAF is going to hurt something else."

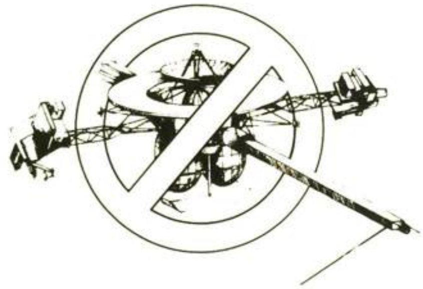
"Well, certainly the basis and validity of the SSEC plan is open to question," Allen responded.

Brad Smith stood up and said, "Edelson has said that TOPEX would be *the* top priority. Now in his printed statement he says CRAF will be *a* top priority."

Rosendahl tried to explain. "There are multiple perspectives to look at. We may have to place a moratorium on adding new projects to the program. Vis a vis Congress, things have changed radically. This postponement has nothing to do with the merits of CRAF."

Joe Veverka chimed in, saying Edelson's statement "has raised doubts rather than reassuring any of us here."

By the time the discussion ended, everyone seemed tired and slightly cranky. The issues were big ones, almost too big to deal with, and no one present had any real control over the larger societal forces that will inevitably shape the space program. It was near the end of the evening when Bill Green pointed out the obvious: "The public doesn't understand the choices that are being made."



In the days that followed, the planetary astronomers gave papers and listened to those given by others. Topics ranged from the fascinating to the opaque. In the Pluto session, for example, Jim Beletic described his improved ephemeris for Charon. Based on 700 minutes of speckle interferometry data taken over 7 nights, this work was of interest to many astronomers because it will improve predictions of the ongoing Pluto-Charon mutual eclipse series.

Ed Tedesco of JPL/CalTech showed light curves for a dozen or so Pluto-Charon eclipses and occultations that occurred early last year, and R.S. Dunbar explained his detailed analytical model of these light curves. By matching the observed events to the predicted light curves, it will ultimately be possible to derive low-resolution surface maps of both Pluto and its satellite.

David Tholen of the Institute for Astronomy in Hawaii used orbital data and eclipse timings to determine the total mass of the Pluto-Charon system (roughly 6.8 x 10^{-9} solar masses) and establish new upper and lower limits on the size of Pluto. His numbers imply that Pluto can be no denser than 1.1g/cm^3. This means that Pluto can't contain much rocky material but is mostly water ice.

Mark Buie presented (in less than ten minutes!) the final results of his Lunar and Planetary laboratory doctoral thesis work with University of Arizona astronomer Uwe Fink. Buie used a computer model to generate artificial spectral line profiles of various combinations of methane frost and an overlying methane atmosphere, which he then compared to actual spectral line profiles of Pluto at various times in its rotation. A model with two methane frost spots on the planet's surface and a thin methane atmosphere partially satisfied the obervational data but could not reproduce it exactly. Buie suspects that the size of the particles in the frost affects the spectrum.

The final paper in the Pluto session was presented by Robert Marcialis, who set out to predict the surface topography of Pluto based on what we know of the planet. It turns out that we know very little about the temperature/viscosity relationship of water and methane mixtures thought to compose the top 60 kilometers of Pluto. Certainly the water ice layer under Pluto's crust is hard and the methane/water crust is fairly soft.

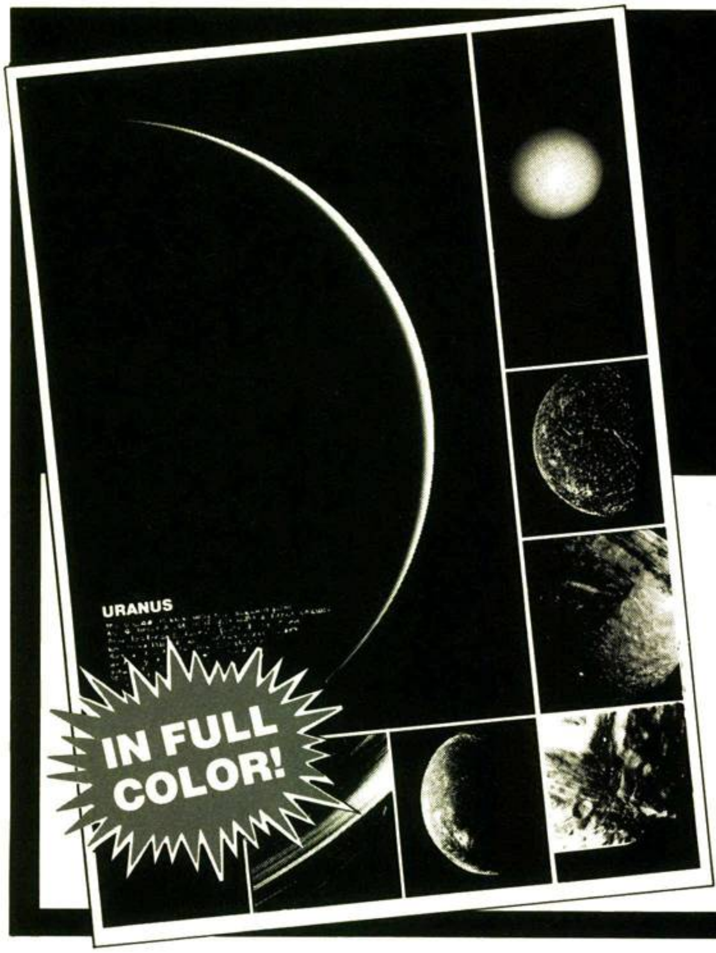
With Voyager rapidly approaching Uranus, I half expected to hear papers offering daring predictions of what we'll find there — echoes of the famous "Io will have volcanoes" paper that Stanton Peale, Pat Cassen, and Ray Reynolds presented shortly before the first Voyager flyby of Jupiter. The only such paper — well, certainly the most dramatic — came from Glenn Orton of JPL. While assembling a complete infrared spectrum of Uranus from 2 micrometers to 3 millimeters wave-length, Orton found that the complete spectrum did not make sense unless he used 30 percent helium in his models of the Uranian atmosphere, a percentage far greater than conventional theories of planetary formation can account for.

Orton added that the additional helium could create all sorts of problems. It would raise the mean molecular weight of the atmosphere, change its temperature, alter the overall density of the planet, distort the accepted refractivity profile, increase the atmospheric opacity by a factor of five, and change the moment of inertia of the planet — all factors that are thought to be reasonably well established.

"Helium is the simplest thing that explains the shape of the spectrum" Orton said. Although he didn't like it one bit, he couldn't explain it away. He added that "those who think Uranus is some sort of mini-Jupiter or mini-Saturn are in for a big surprise."

I was delighted. I *like* planets like that.

— Richard Berry



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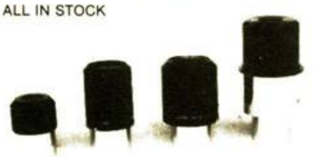

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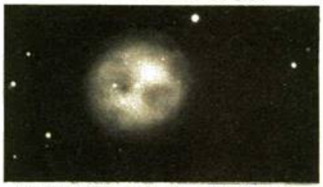

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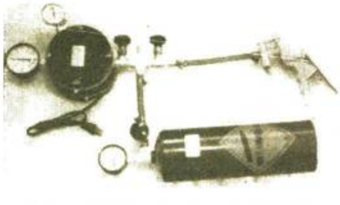

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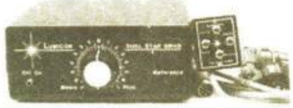

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See Meade 2080/LX2 options	
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Model 320 ($900 list)	$630

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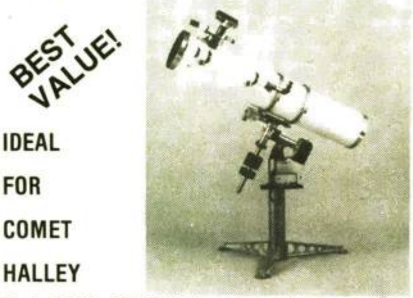

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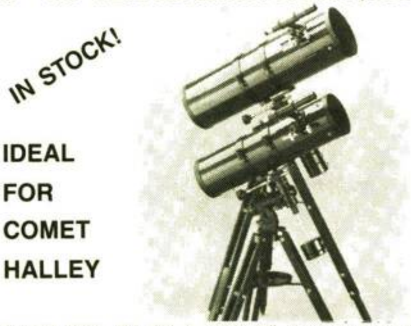

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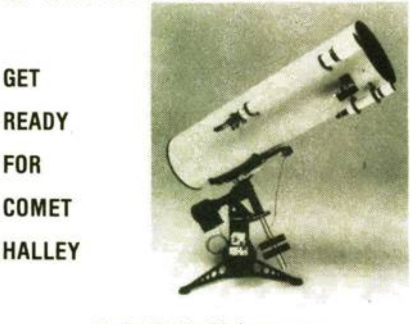

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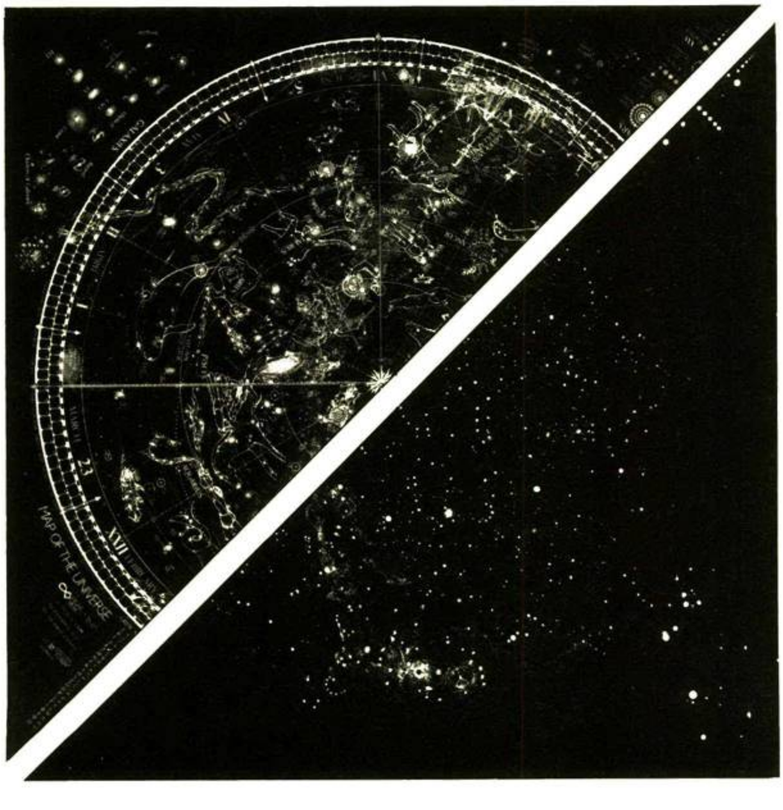

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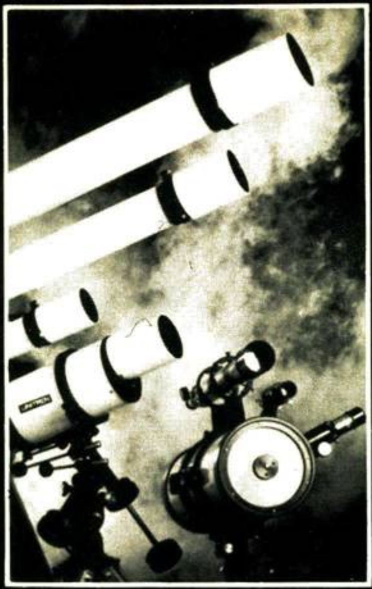

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ASTRONOMY
In Focus

Professor van de Kamp

Sir / I envied Govert Schilling his opportunity to talk shop with Peter van de Kamp (Forum, December 1985). Professor van de Kamp is known for more than "seeing" planets beyond our solar system and playing the violin with Einstein, however. For several decades he skillfully taught at Swarthmore College, conveying the excitement of astronomy to his students (myself included in 1949-50). He also played the piano beautifully as an accompaniment to silent screen classics.

Evans H. Burn
Sherborn, MA

Solar Projection With Binoculars

Sir / As a binocular astronomer for many years and as author of a forthcoming book on the subject, I particularly enjoyed David H. Levy's "Discovering Binocular Astronomy" (Equipment Atlas, December 1985). Simply not enough good information exists about this wonderful hobby.

Levy's information was solid and concise, yet I would firmly caution against the popular method of projecting the Sun's image through 50mm or larger binoculars. Heat is no friend of a closed instrument that often possesses sixteen or more optical elements.

A 50mm cemented doublet may focus sunlight for quite a while before heat absorbed in the glass softens the Canada balsam cement between the lens elements and causes them to separate. This problem is especially critical in 11x80 and 20x80 binoculars. Not only are the objectives at risk in solar projection, but the Erfle and Kellner eyepieces face an even stiffer test. The oculars are at the focus where the Sun's heat is most intense. A fried, bubbly, and separated eye lens may result.

Another problem with solar projection is that heating can eventually make the instrument's lubricant run, which may drip into the eyepieces. There is also a risk of prisms overexpanding their slots and clamps, thus chipping or fracturing them. Expanded prisms may also cause permanent flexure in some bronze prism clamps and make for loose prisms.

If you must project the solar image with your binoculars, then do it only for seconds at a time and never with giant binoculars. If you want a casual and safe view of solar activity, then I recommend buying some inexpensive aluminized Mylar filters that can be securely fitted over the binocular objectives.

Steve Mensing
Philadelphia, PA

Halley Haiku

Sir / When my eight-year-old rushed in from the mailbox and poked your October issue in my face, I saw in him a reflection of myself at his age and the excited anticipation of the event that 1986 will bring. Your issue revived that boyish wonder in me.

Since Asian cultures did so much to keep records of Halley (even though they didn't understand what it was), I felt it appropriate to compose a haiku in their honor:

Hail! Comet Halley
Once revered as soothsayer
You dazzle, resolved.

John Ray
Rockville, MD

Aussie Lights Out for Halley

Sir / A major campaign has been launched by a number of amateur astronomers in the Australian state of Queensland and elsewhere around the country for a total blackout of all government and commercial lighting. The target dates and times are: March 14 and 15, 2:30 a.m. to dawn; April 4 and 5, 7:30 to 10:30 p.m.; and April 11 and 12, 10:30 p.m. to 1:30 a.m. These nights will be the best times to view the comet.

Here in Brisbane, a campaign was launched only for the city. I felt this discriminated against the rest of the state, so I wrote a letter to the Premier, Sir Joh Bjelke-Petersen, outlining my thoughts. At the time of this writing (December 12, 1985), my letter has fallen on favorable ears. While the city's chances for a "lights out" are looking good, the prospects for a statewide "lights out" are even better.

If any overseas or Australian visitors are planning to stay or pass through Queensland around the times listed, viewing Halley's Comet from the "Sunshine State" will be to your liking.

In New South Wales another campaign is underway; the Wran Labor Government is considering turning out the city lights in Sydney. Other capitals around the country are moving in similar directions so if things work out, as they look like they will, Australia will be *the* place to be for Halley's Comet in '86.

Jim Barclay
Sun Coast Astronomical Society
Queensland, Australia

Diffraction-Limited Newts

Sir / I enjoyed the article by Robert Buss on making a lunar-planetary reflector (Equipment Atlas, July 1985). I've been saying for a long time that f/7 and longer Newtonians would have a resurgence of popularity when people rediscovered how well they performed. It's good to see that someone else has the same opinion.

I disagree with a few points that Mr. Buss made in the article, though. In spite of the care he took to eliminate the diffraction caused by the mirror clips, he advocated using a single-vane spider. I once made a spherical f/12 lunar-planetary Newtonian with a single-vane spider. Although it performed admirably (making lunar-planetary telescopes is an exercise in nit-picking), I got the definite impression that the most important residual error was caused by that vane. The diffraction it causes is the same as that caused by a wide slit, which produces thin, weak spikes associated with narrow vane spiders. Oddly enough, long weak spikes often look *worse* than short strong ones, but you've got to keep in mind where the light is going and what image it is disturbing.

Diffraction spikes offer no problem in the separation of double stars. If an offending spike is in the way, you just reorient the tube. The problem is not so easily solved in the case of planetary detail.

I have had some favorable experiences with closed-tube Newtonians so I'd say the method of choice for supporting a diagonal is an optical window. But barring that, I suggest the conventional approach of using a tensioned thin-vane spider with the thinnest possible vanes and taking extra care to orient the vanes perpendicular to the mirror. Some experimentation has been done on adapting thin wire to hold the secondary, and a courageous telescope maker might try this method. If the diffraction spikes are that objectionable, you could possibly mount the very small secondary mirror on a reasonably thin, 90-degree curved vane.

Another thing I disagree with is the rather tight restriction on the tube diameter for the sake of lowering the focus distance. I found in my f/12 scope that making the tube a full inch larger in diameter than the mirror more than paid for the tiny increment in diagonal size. Currents of air in the tube are less of a problem in this telescope than in any tubed Newtonian I have ever seen because they occur out of the optical path. Since diagonals come in fixed sizes, you usually have a little extra minor-axis diameters to play with, anyway.

One point I would add is the importance of obtaining a good mirror. In long focal ratios, excellent mirrors are available at quite reasonable prices. Unfortunately, a bad mirror might sneak in anyway. If you are working alone, I advise you to read the article on star testing published in the April 1983 issue of ASTRONOMY. If a local club is available, then find a mirror maker to test the mirror before you drill the tube. Pay special attention to the condition of the edge and overall smoothness of figure.

Telescope Making #23 has an article by Gregory Reeve titled "The Ultimate Newtonian." I believe Reeve said it best when he commented that there is no single change that can make the usual Newtonian give refractor-like images, but rather an "accumulation of small victories" that leads to eventual improvement. I believe that a more sophisticated spider and a slightly enlarged tube represent two "small victories" that are easily attained.

Dick Suiter
Panama City, FL

Early View of Halley

Sir / On Saturday, September 18th, I drove 35 minutes away from Minneapolis to a site where the Minnesota Astronomical Society holds star parties.

The night was fantastic; in fact, I felt the sky darkness was almost as good as the 1984 Texas Star Party. While I waited for Orion to rise — and with it Comets Halley and Giacobini-Zinner — I went wild finding emission and dark nebulae throughout the summer Milky Way. Armed with my 10.1-inch Dobsonian, 11x80 binoculars, Sony Walkman, and a UHC filter, I found every nebula I searched for.

As Orion rose, some cirrus clouds in the east threatened to disappoint me, but they kept their distance. When the right area was high enough, I quickly found the region where Halley was supposed to be. Using magnifications of 80x to 240x, I clearly spotted a star-like object precisely in the spot where Halley should have been at 9 UT on Sunday morning, September 19th. This object appeared to be no brighter than 13th magnitude. There were no other objects brighter than 14th magnitude indicated on my finder chart; therefore, I am convinced I saw Halley!

Patrick W. Drigans
Fridley, MN

Ooops!

The photo of a Perseid meteor streaking across star trails on page 139 of the October 1985 issue was taken by Craig Stott, not David Stott. Our apologies for the error.

Behind the Scenes

Waiting for Encounter

Pasadena, Ca.; January 20 — A few days from now, the Voyager 2 spacecraft will speed past the planet Uranus. Under the control of its on-board computer, cameras and instruments will step through pre-determined sequences of pointing, exposure, and read-out. Encoded as bits in a digital data stream, the various output signals will be mixed, then passed through Voyager's radio transmitter and sent into space.

The signals will travel for two and a half hours before they reach Earth. Here a tiny fraction of the radio energy beamed into space will be picked up by the Deep Space Network's giant antennas in Spain, Australia, and California. Amplified and relayed to the Jet Propulsion Laboratory in Pasadena, the Voyager data stream will be taken apart, calibrated, refined, and reassembled into images or read-outs of light intensity and signal strength by the powerful mission control computers.

However, it isn't until humans scratch their heads over the meaning of the wavy lines on the charts, the unexpectedly high or low signal, and the features seen or not seen that voltages, bits, numbers, and data become meaningful information.

Despite the powerful tools we now employ, we need to bring intellect to bear on that information before it becomes knowledge. Unless someone interprets the patterns of dark and light in the images as features, compares them with the features seen on other planets, and speculates on the processes that might be causing what we see, the universe is neither richer nor more meaningful.

The findings from the Uranus flyby — spoken by scientists who have interpreted the incoming data, heard by an audience of reporters from around the world, keyed into computers where information again becomes bits, carried over phone wires as electrical signals, stored in another computer's memory, developed as marks on lithographic plate, and printed with ink on paper — will be read and hopefully understood by humans who will shake their heads in wonder at the knowledge so recently gleaned from a planet they can hardly imagine.

Sincerely,

Richard Berry

Richard Berry
Editor-in-Chief

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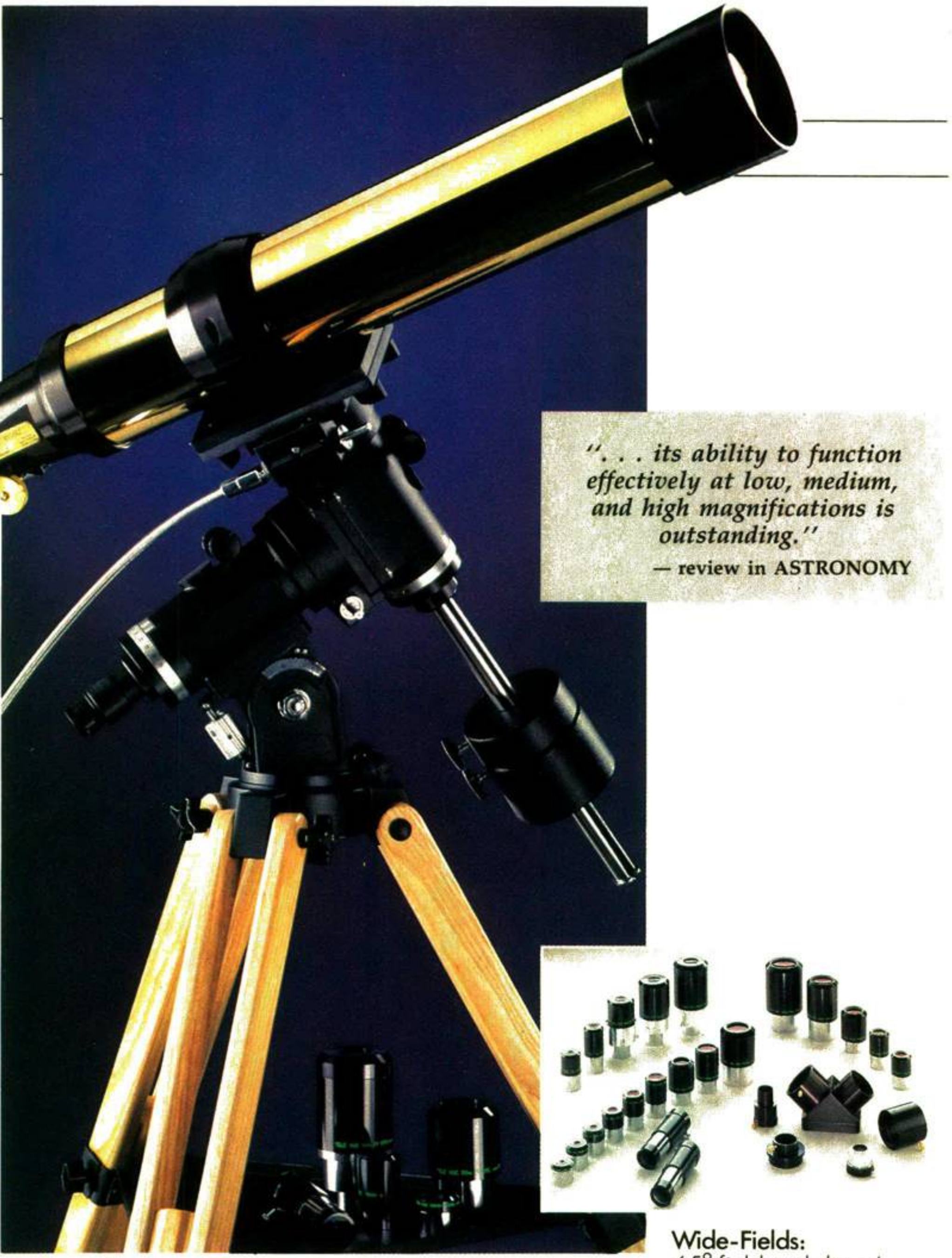

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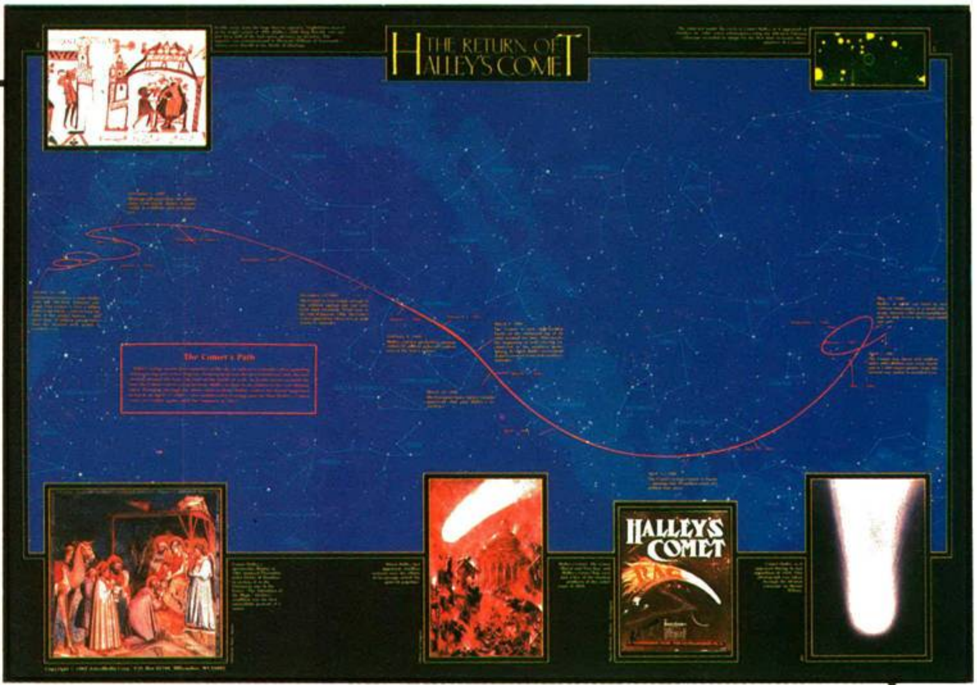
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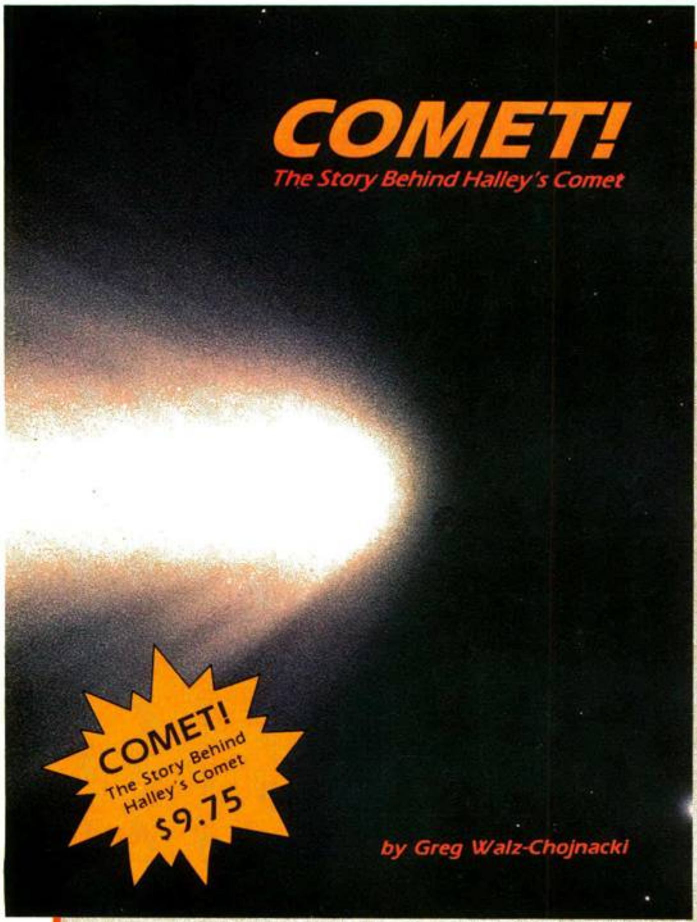
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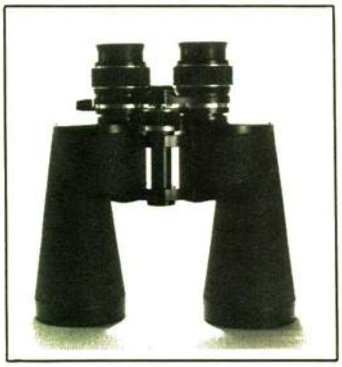

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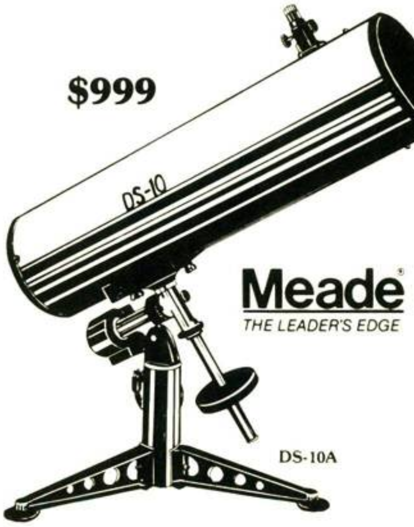

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Halley Plunges Behind the Sun

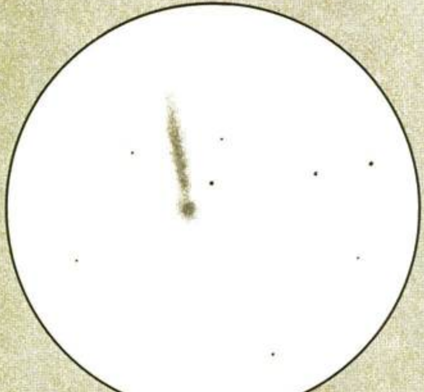
Half the show was over. In mid-January 1986, Halley's Comet — then a 4th-magnitude fuzzball hanging low in the southwestern evening sky — was sinking fast into the twilight. Its passage to perihelion on February 9 brought the comet close enough to the Sun to remain invisible until the last week of February.

The pre-perihelion views of Comet Halley were history. Backyard astronomers who had nervously checked the sky each hour during afternoons on moonless days, who purchased yards and yards of hypered film and kept it at the ready, who had spent hours marking the comet's movements across the sky on their trusty star atlases suddenly had nothing to look at for six weeks. All they could do was reflect on their past observations of Halley's incoming journey.

Halley's behavior had at first been discouraging — it seemed destined for dimness — but then it dramatically brightened. During August and September 1985, it was a 14th-magnitude spot of light that was seen only by the relatively few amateur astronomers equipped with large telescopes. In October the comet began to brighten, rising to 9th magnitude by the middle of the month. November saw the comet swell in brightness and pass right beside the dipper-shaped Pleiades cluster in Taurus. By December, Halley's famous snowball had grown immensely to cover the angular size of the Moon. Even though it shone at 5th magnitude, the comet's surface brightness — the amount of light per unit area — was still rather low, causing disappointment for those who expected a brilliant fireball but instead saw a subtle, nebulous cotton ball. By mid-January when it left the sky, the comet shone at 4th magnitude and sported a faint tail that was visually 3° long. During this six-month period thousands of backyard stargazers across the world saw Halley and seemed to be satisfied with the comet, although many of them remembered seeing far brighter comets like West, Bennett, and Ikeya-Seki.

David R. Keedy of Tyne and Wear, England, remembered his first sighting of Halley: "For the past thirty-five of my forty-two years I have looked forward to seeing Comet Halley. On October 14, 1985, I made an unsuccessful attempt to observe the comet using 11x80 binoculars. Then came four cloudy nights when viewing was impossible. The suspense was almost killing me.

"On October 19, using the same binoculars, I managed to glimpse Comet Halley. It was about magnitude 9.5 and slightly fuzzy in appearance. The comet wasn't easy to see because my arms were shaking with the cold and fatigue, and my eyes were tired.



During late January observing Halley's Comet was hampered by a bright Moon as it sank into the evening twilight. But on January 14 its bright coma and 3-degree tail were still visible in 20x80 binoculars. Sketch by David J. Eicher.

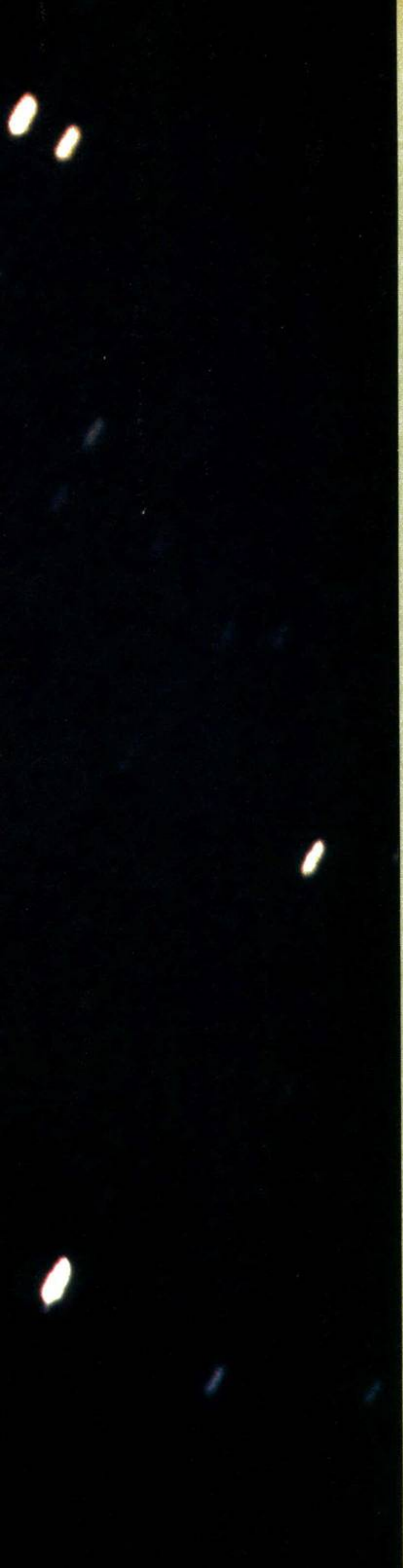
"Surprisingly, although I was pleased to see the comet, I was not greatly thrilled. I had expended so much nervous energy in anticipation that I felt drained when I finally found the comet. Nevertheless, I had waited patiently for thirty-five years, so I still savored that moment when I first saw Comet Halley."

Along with many other stargazers, Charlene Phillips of College Corner, Ohio, monitored the comet regularly: "My husband and I have followed Halley's Comet since November 8, 1985. At that time we located it in Taurus. Since then we have made twenty-six observations (with a lot of cloudy nights between them!) but have yet to see it with the naked eye. We do have a bit of light pollution, but we live in a small town where the sky can be really dark. The comet has brightened considerably since our first sighting when it was barely visible in 7x50 binoculars. Now Halley has passed through the Water Jar of Aquarius and, we believe, was just slightly dimmer than Gamma (γ) Aquarii."

Curiously, many city-bound astronomers have spotted Halley's Comet from relatively light-polluted locations. And, thankfully, the comet became bright enough to permit even serious study from a light-polluted sky. Astronomer Gerard de Vaucouleurs of the University of Texas at Austin wrote: "I have been following the comet, weather permitting, from Austin in spite of the hindrance of light pollution. (It is hard to see 3rd-magnitude stars with the naked eye.) I obtained the following integrated magnitudes with an 8x30 binocular used way out-of-focus (image diameter = 15′). The comparison stars were o = 31 Aqr (V= 4.74), π = 52 Aqr (4.66), 32 Aqr (5.29), 60 Aqr (5.87), and the derived magnitudes are as follows: December 29 (UT): 5.6, December 30: 5.5, December 31: 5.3, January 1: 5.2, January 3: 5.1, January 5: 5.0, January 6: 4.9." Clearly, the comet was continuing its sharp increase in brightness.

Young amateur astronomer Ted Ollier, also in Austin, was keeping track of the comet as well. He wrote: "I first spotted

Right: Paul Roques was one of the first backyard astrophotographers to capture Halley's gas and dust tails as distinctly separate entities. This photo was made on January 10 using a 4-inch f/2.64 Schmidt camera, hypered Tech Pan film, and a 30-minute exposure.



Above: A night before Schur's photo was made, Paul Borchardt recorded Halley using a 600mm f/6 lens, hypered Tech Pan film, a minus-violet filter, and a 15-minute exposure.

Left: The shape and structure of Halley's tail changed dramatically as photographed by backyard astronomers. When Chris Schur made this photo on December 30, the gas tail was a long thin spike. This is a 30-minute exposure on 3M 1000 film made with a 16-inch f/4.5 reflector.

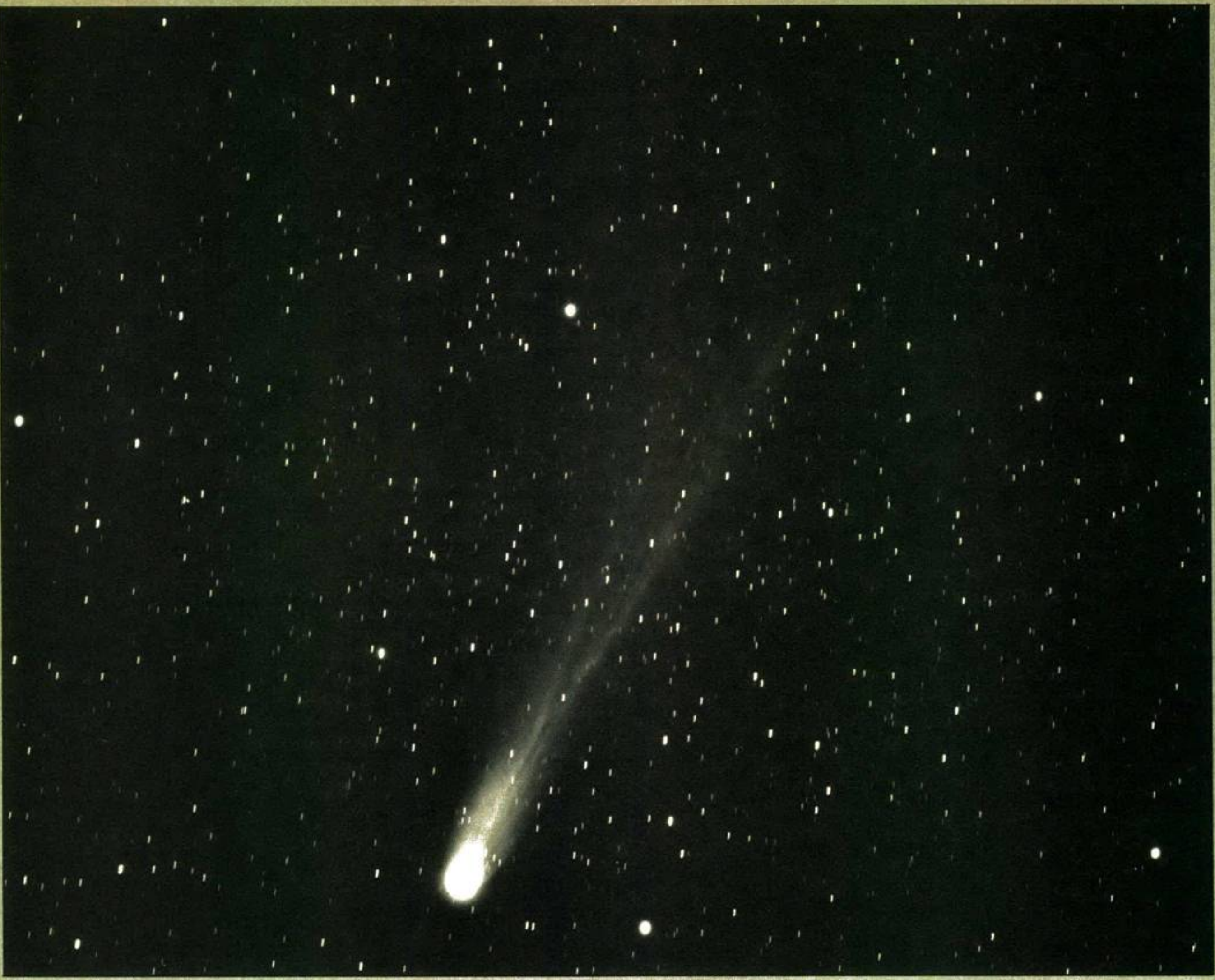
Halley on December 5 with the help of my 7x50 binoculars. It was a faint fuzzy blob with a diameter of about 30′. I tracked it until the 9th when cloudy skies ruined the rest of the observing window.

"The observation that Halley will attract many people to amateur astronomy is right. My friend Zachary Simpson called me at least five times on the 6th, saying he never really figured out where Pegasus was. I had to go to his house the next night to straighten him out. That was the best night of observing so far, despite small clouds that kept drifting in. Halley's Comet was much brighter than before and we could make out a faint tail that stretched out of the field of view."

Joseph A. Bligh of Lakewood, California, told the painful truth when he wrote: "It is very difficult for the amateur with binoculars to find the Halley's Comet fuzzball in the lit skies of Los Angeles."

Naked-eye sightings were rare in November but became commonplace by December. William R. Carney of the Twin City Amateur Astronomers of Bloomington, Illinois, described his initial naked-eye sighting: "The first time I recall observing the comet 'naked-eye' was during the first week of December. Several members and I observed Halley on December 6 during a public viewing session. During the week that followed we saw Halley naked-eye on four more occasions. Besides being barely visible as a fuzzy patch with unaided eyes, the comet was a very good object in binoculars and small telescopes."

Roberto Saldana Polo of the U.S. Army's 32nd Artillery at Fort Stewart, Georgia, wrote: "I've been spotting Halley's Comet since October 10, when I first recognized it, with my 30x70 binoculars and the charts you've been publishing. A lot of people are looking for me these days just so they can see Comet Halley! The best nights of viewing I had were December 9 and 10 when I saw Halley with the naked eye from a dark sky after finding it initially with binoculars. On December 10



Above: In mid-January, after Halley's tail grew large and before the comet slipped into the sunset, backyard astrophotographers captured stunning detail in the comet's tail. This photograph shows gas and dust tails, the gas tail containing details such as knots, spikes, rays, and kinks — all trademarks of a well-developed gas tail. Photo by Jim Riffle using a 12-inch f/5 Astromak telescope, hypered Tech Pan film, and a 30-minute exposure.

Left: Marco Milani photographed Halley on December 11 just as a gas tail was beginning to form. He used a 10-inch f/4.8 Newtonian, 3M 1000 film, and a 15-minute exposure.

the comet entered the Circlet of Pisces and was a very impressive, bright object."

On those same nights, Asit Choudhuri spotted the comet from Campinas, Brazil, and wrote: "We live on the outskirts of the city so that our sky is dark and clear and ideal for comet watching. Thanks to your charts we saw Halley on November 30 and tracked it along on December 9, 10, and 12 from our backyard. You can imagine how excited we were to see the small nebulous patch."

Viewers in Colorado seemed to have especially good luck with Halley. Myron Cook of Colorado Springs wrote: "Using the program that computes the ephemeris of Halley's Comet provided by Roger Browne in your February 1985 issue, I had been computing the daily positions of the comet, marking them on *Sky Atlas 2000.0*, and trying to catch my first glimpse of Halley. Using a pair of 7x35 binoculars I looked on each clear night. On December 4 I had my first successful observation; the position I had plotted on Tirion's atlas matched a tiny, fuzzy, blue, diffuse object in the sky. I had seen Halley! I didn't know how to estimate its magnitude; finding it was enough for me. I hope that Halley will now put on a better show than the early conservative reports indicated."

From Longmont, Colorado, Michael J. Hutchinson saw Halley as "a difficult, faint diffuse object in 7x50 binoculars" on November 15 when it lay just south of the Pleiades star cluster. Early in January, he saw Halley as a faint naked-eye object.

David H. Levy viewed Halley from his backyard outside Tucson, Arizona, using a 16-inch f/5 reflector. On January 6 he saw Halley's large detailed coma, which showed "two large fans of nebulosity curving outward from the inner coma." The nucleus was bright and oval, Levy reported. But the fantastic part about observing Halley with a big scope during January was the ion tail, which Levy described as "a monstrous tail stretching over 3°; it was narrow, delicate, and contained exquisite little strands of light."

I had my last pre-perihelion view of Halley on January 14, some 35 miles north of Milwaukee. A slim crescent Moon hung high in the southwest not far from the comet. Halley was easy to find but not terrifically impressive, largely due to scattered moonlight. The nucleus and coma were bright and a faint tail showing little striations and knots stretched some 2.5° toward the zenith. I sketched the comet using 7x42 and 20x80 binoculars and a 4¼-inch reflector. Then I said goodbye to Halley, packed up, and left.

On the drive back home I remembered something Levy had said: "Often, as with Halley, you can tell if a comet is bright because it's nearby or is intrinsically bright and detailed — a big comet. Believe me — Halley's Comet is a big one."

— David J. Eicher

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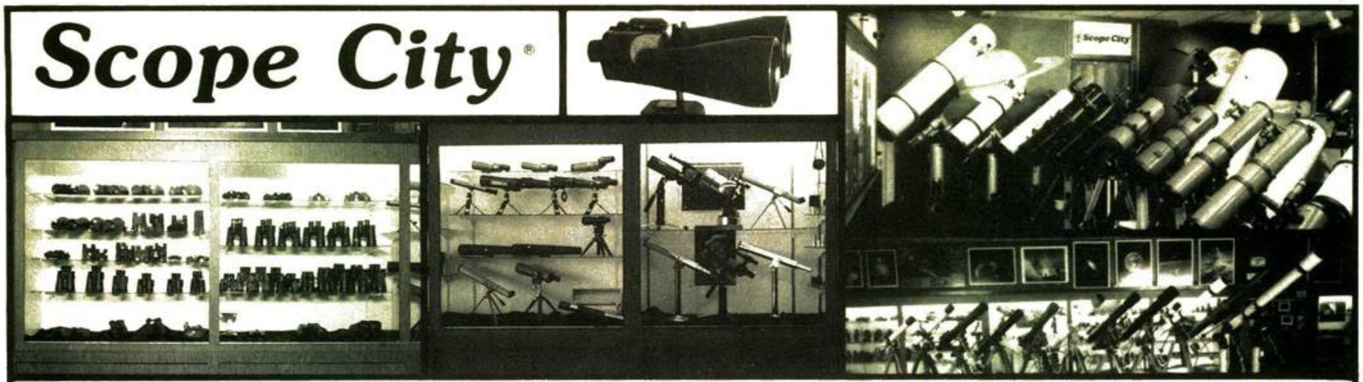

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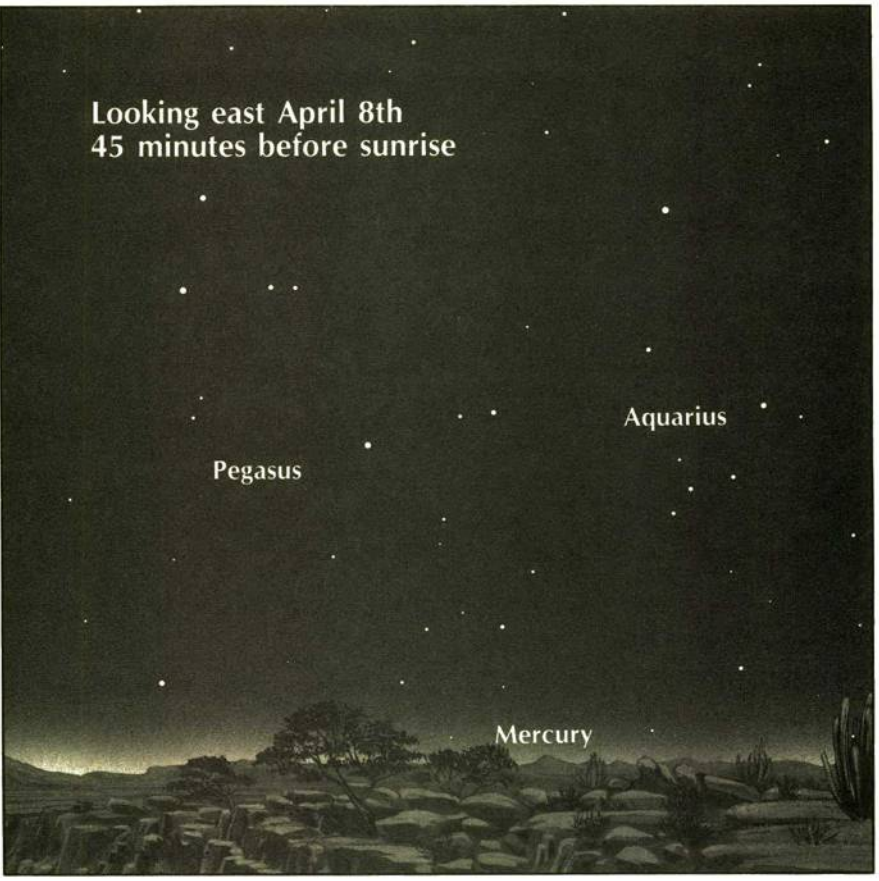
Curtain Call for Comet Halley

by Fred Schaaf



The Wanderers

April is the last month for a good look at **Halley's Comet** during this return. We won't see it so bright again for another lifetime. Many amateur astronomers will be walking around with one sad refrain in mind this month: "Oh, how I'd rather be in the Southern Hemisphere!"

While the view of Halley from below the equator is undeniably better, it's not all that bad for northerners. Even when the comet is farthest south (April 9), its head climbs a few degrees above the horizon in the middle of the night for observers at 40° north latitude and at least its tail ought to be visible above the horizon murk.

As April begins, the comet is visible low in the eastern predawn sky. Best Moon-free viewing times are from the 2nd until the 13th, though under increasingly moonlit conditions you can observe until perhaps as late as the 21st. Then try again from the 28th to the 30th when the comet will be visible low in the western evening sky. (See last month's Gazer's Gazette for detailed finder charts and directions.)

Only one naked-eye planet is in the evening sky: −3.9 magnitude **Venus**. It is the conspicuously brilliant white "star" above the western horizon during the hour after sunset. Following Earth in its own orbital track around the Sun, Venus will hold a prominent position in the evening sky until early autumn, with the constellations of spring and summer sliding down westward night-by-night behind it.

The morning sky during the hour before sunrise contains the rest of the naked-eye planets (as well as Halley during the first half of April). Farthest to the west as morning twilight begins is 0.3 magnitude **Saturn**, a creamy white dot of light about 7° north of the star Antares in Scorpius (which it passes directly north of on the 16th). Saturn is moving slowly westward against the background stars.

For information on viewing the Moon, planets, and deep-sky objects with telescopes, see **The Backyard Astronomer**.

To the east of Saturn, and just about due south at the start of morning twilight, is the Red Planet **Mars**. Tawny orange in color, Mars will brighten swiftly as the weeks pass: on the 1st it is at magnitude 0.1, and by the end of April it will have gained more than half a magnitude to shine at −0.6. (At opposition on July 10, Mars will be at −2.7 magnitude.) On April 8, Mars passes a degree and a half south of **Neptune**, though only Mars will be visible unless you are observing with binoculars or a small telescope. At magnitude 7.9, Neptune is too dim to be seen by the naked eye.

Almost the last planet to rise in the morning sky is **Jupiter**. This −2.1 magnitude planet is in Aquarius, a dim constellation, but is easily identifiable as a bright object low in the east-southeast.

Mercury reaches greatest western elongation from the Sun (28°) on April 13, but since its orbital path lies at a very shallow angle to the horizon, the large separation from the Sun's glare is wasted. Look for a bright dot of light about 2° high in the east for a few days around April 8. Mercury will be substantially dimmed and somewhat reddened by its low elevation. Binoculars will greatly help you to find the planet.

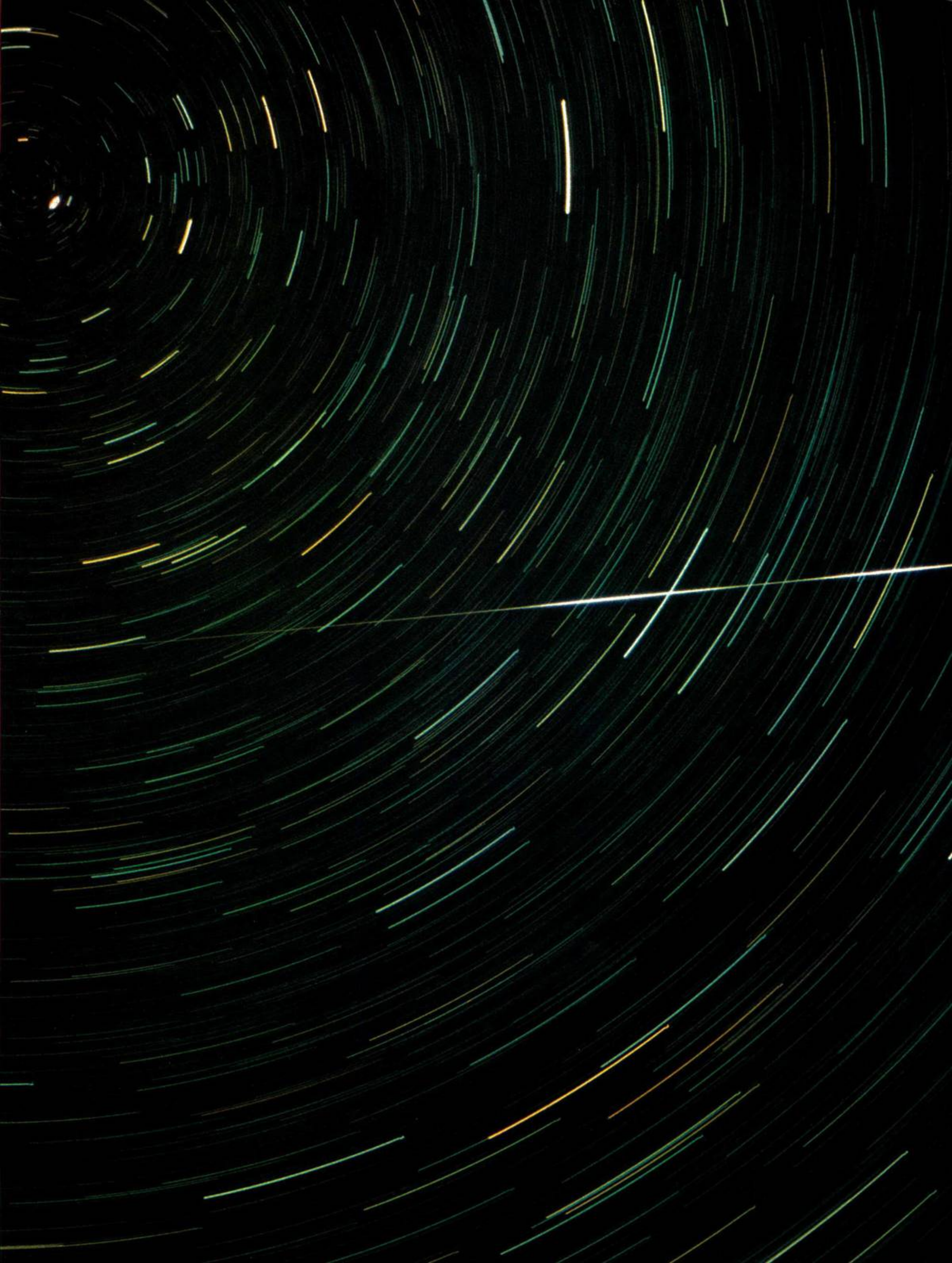
In early April, as the Moon becomes New on the 9th, Australia and neighboring lands in the southwestern Pacific will get to see a **partial solar eclipse**. Two weeks later, the western parts of North America will witness part of a **total lunar eclipse**. Maximum eclipse occurs at 4:44 a.m. Pacific Standard Time on April 24, with the Moon setting as morning twilight brightens. Totality lasts 64 minutes, during which time viewers across the Pacific (especially in Polynesia) and in Australasia will see Comet Halley just 40° from the ochre-colored Moon.

Right: A bright fireball meteor streaks across north polar star trails. Photo by Tim Pickering, who used a 50mm lens and a 1-hour exposure at f/2 on Kodak's VR 400 film.

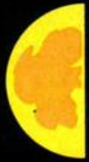
The Starry Sky

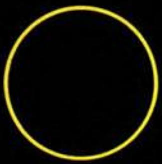
In the spring, **Ursa Major** the Great Bear hangs high overhead in the northern sky. Also known as the Big Dipper, the Plough, and Charles' Wain, this easy-to-spot constellation is visible year-round to observers in mid-northern latitudes. Yet the Big Dipper is at its best on spring evenings when it swings far up over the Pole Star.

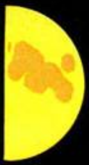
The Big Dipper's stars form a large, striking pattern: the top of the bowl stretches 10° across and the entire dipper measures 25°. The two stars on the outside of the bowl are the famous Pointers,

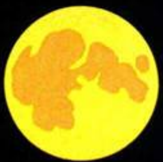


April Night Sky


Last Quarter
April 1
2:30 p.m. EST


New Moon
April 9
1:08 a.m. EST


First Quarter
April 17
5:35 a.m. EST


Full Moon
April 24
7:46 a.m. EST

1st The Moon reaches Last Quarter at 2:30 p.m. EST.

2nd Halley's Comet is visible in the morning sky from today until the 13th without moonlight interfering and until about the 21st with some interference.

6th The crescent Moon passes 3° south of Jupiter in the morning sky.

8th Mars overtakes Neptune, passing one-and-a-half degrees south of it.

9th New Moon is at 1:08 a.m. EST; a partial solar eclipse is visible in Australia and the southwestern Pacific.

10th Venus lies a little over a degree south of the Moon in the evening sky.

13th The Moon is farthest from Earth at 7:01 a.m. EST: 251,978 miles. Mercury is at greatest elongation west in the morning sky, but this is a poor apparition.

17th First Quarter Moon is at 5:35 a.m. EST.

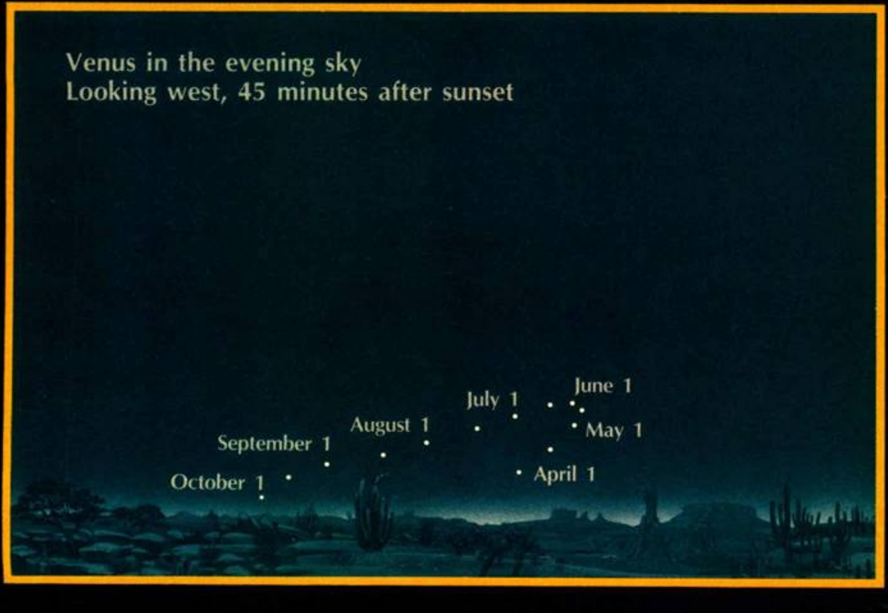
24th Full Moon occurs at 7:46 a.m. EST; a total lunar eclipse is visible at moonset from the western coast of North America and earlier in the night over the Pacific Ocean.

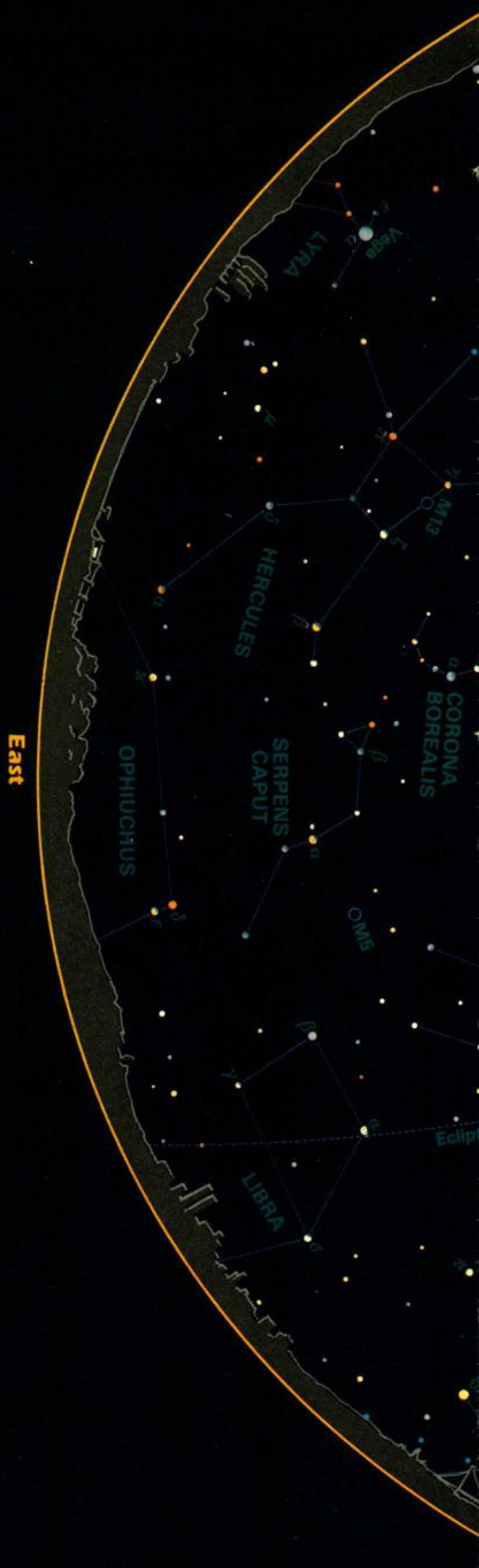
25th The Moon is closest to Earth at 12:41 p.m. EST: 223,291 miles.

26th Pluto is at opposition. The Moon passes near Saturn and Antares.

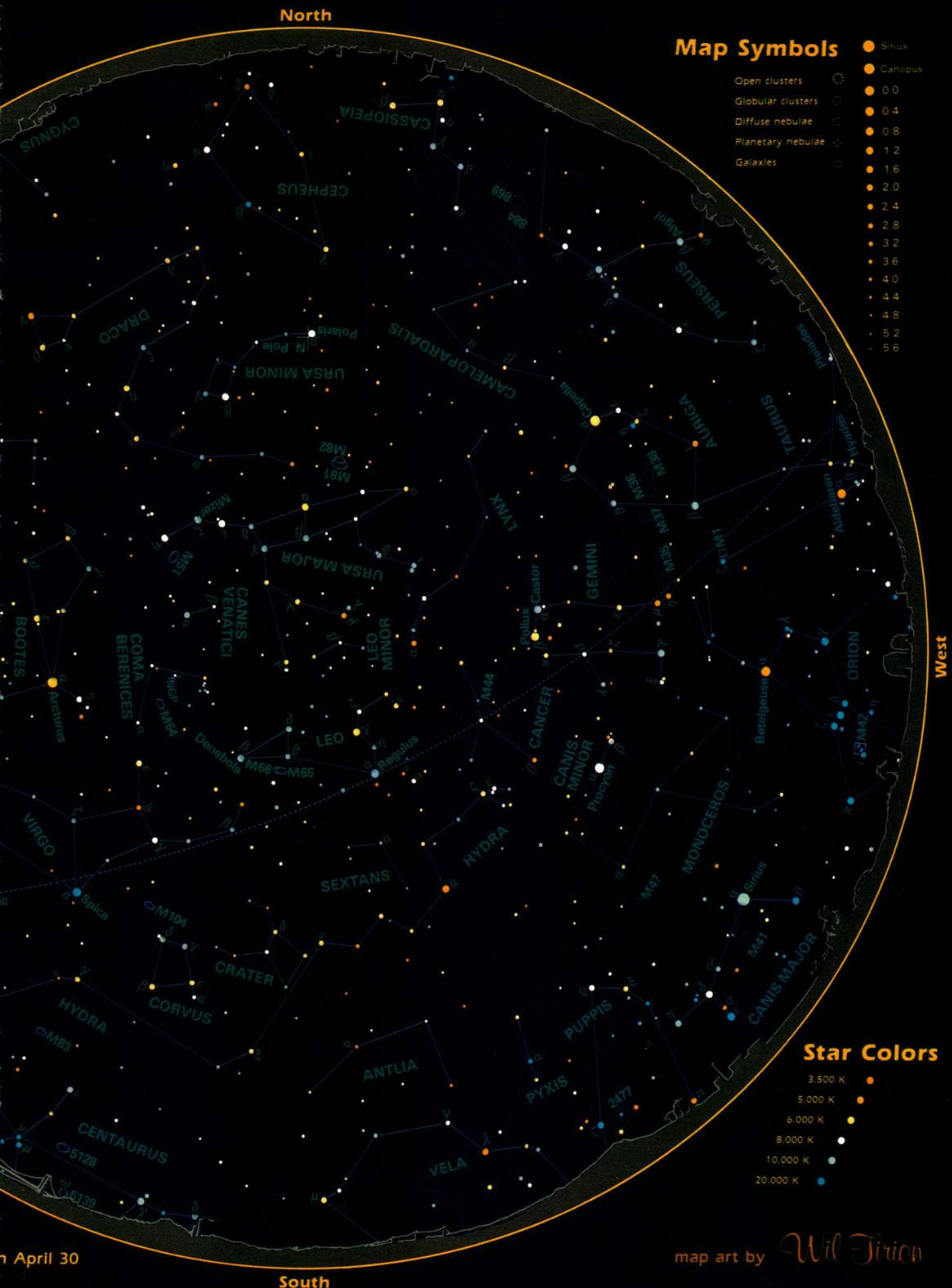
28th During the next few days, look for Halley in the evening sky.

29th Mars lies 4° north of the Moon in the morning sky.


Venus in the evening sky
Looking west, 45 minutes after sunset



9:30 p.m. on April 1
8:30 p.m. on April 15
8:30 p.m. (Daylight Savings Time) o


North
Map Symbols
Open clusters
Globular clusters
Diffuse nebulae
Planetary nebulae
Galaxies
Sirius
Canopus
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
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5.2
5.6
CYGNUS
CASSIOPEIA
CEPHEUS
869
884
Algol
PERSEUS
DRACO
Polaris
N. Pole
URSA MINOR
CAMELOPARDALIS
Pleiades
Capella
AURIGA
TAURUS
Hyades
M82
M81
M38
M36
M37
Aldebaran
Mizar
LYNX
M51
URSA MAJOR
M35
M1
CANES VENATICI
Castor
GEMINI
BOÖTES
COMA BERENICES
LEO MINOR
Pollux
ORION
West
Arcturus
NGP
M64
M44
CANCER
Betelgeuse
M42
Denebola
LEO
Regulus
M66
M65
CANIS MINOR
Procyon
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M47
Spica
M104
Sirius
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CRATER
CORVUS
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PUPPIS
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2477
Star Colors
3,500 K
5,000 K
6,000 K
8,000 K
10,000 K
20,000 K
CENTAURUS
5128
VELA
5139
South

n April 30

map art by Wil Tirion

Left top: For observers north of about 43° north latitude, only the tail of Halley will be visible this month. Halley may resemble this photo of Comet Ikeya-Seki taken in November 1965, though its tail will be shorter and dimmer. Photo by Sherm Shultz using a 55mm f/1.8 lens and a few minutes' exposure on Tri-X film. Left bottom: David Gagnon caught a Perseid in the bowl of the Big Dipper on August 13, 1985, using a 50mm lens and a 50-second exposure at f/2 on Ektachrome 400 film.

Merak (β) and Dubhe (α), about 5° apart. The distance from Dubhe to Polaris is a little more than one Big Dipper length.

The two stars at opposite ends of the Big Dipper, Alkaid (or Benetnash) at the handle end and Dubhe, are the only Big Dipper stars *not* physically associated with the rest. The five middle stars are members of an association, stars loosely bound by gravity that are traveling through the Galaxy in the same direction.

Besides pointing out Polaris the Pole Star in **Ursa Minor** the Lesser Bear, the Big Dipper can also be used to locate other stars. Most noted of these is Arcturus in **Bootes** the Herdsman. Find it by following the arc of the Dipper's handle outward until you see a zero-magnitude, orange-colored star in the northeast. As the mnemonic says, "Follow the arc to Arcturus."

The Big Dipper actually accounts for only about a quarter of Ursa Major. To the west of Dubhe and Merak more stars complete the front half of the bear's body and head; the Big Dipper's bowl marks the bear's hindquarters and the handle represents a long, zoologically-preposterous tail. Lines of stars branching south from the Big Dipper form the bear's legs, though most of these are so dim as to require very dark, moonless skies if you wish to trace out the bear in its entirety.

On April evenings when the Big Dipper and Ursa Major lie highest in the north, the bear is depicted upside-down. The Big Dipper pours its contents onto Polaris and the Great Bear lies on its back, clawing at the zenith. The bear's paws are marked by three pairs of moderately bright stars. The middle pair (the brightest of the three) passes nearly overhead at 40° north latitude, just north of a dim little constellation called **Leo Minor** the Lesser Lion. Leo Minor is usually overlooked, wedged as it is between the feet of Ursa Major and the back of the heavens' supreme lion, **Leo** proper.

Turn to face south if you wish to see Leo easily. Leo contains one 1st-magnitude star, Regulus; no other star this bright lies so close to the ecliptic, the Sun's path in the sky. Like Ursa Major's Big Dipper, Leo also has a famous asterism, the Sickle, which represents the lion's head, mane, and chest. Shaped like a backward question mark, the Sickle's southern end is marked by Regulus.

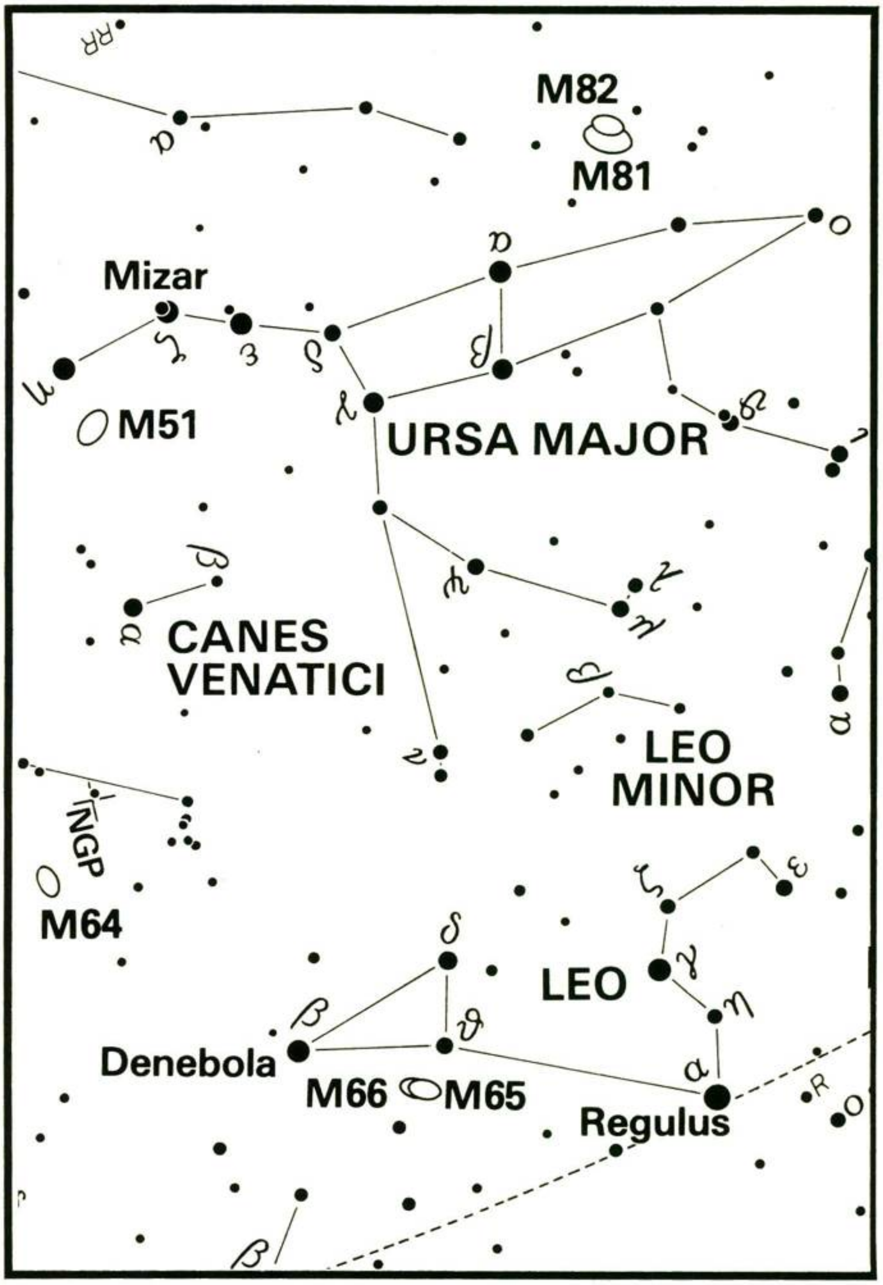
Skylore

The most successful constellation inventors of modern times were Johannes Hevelius and Nicolas Louis de Lacaille; one of the least successful was Edmond Halley. Yet Halley's one constellation did survive for a while, and his fame, grown great again in this year of his comet, brings it back to memory once again.

When young Halley returned from the island of St. Helena where he had been observing and compiling a catalog of southern stars, he announced that he had created a pattern from some of them. He called his constellation Robur Carolinum, "Charles's Oak," which referred to the tree that King Charles II once hid in for two days to escape from Cromwell's forces.

Whatever Halley intended by flattering his king, Charles was sufficiently pleased to do Halley a royal favor: he conveniently waived the need for Halley to return to his classes at Oxford and, by decree, awarded him his master's degree. (Halley had dropped out of school to undertake the southern survey.) Although Halley's starry tribute to Charles II has not endured, it was still found on star atlases as late as the mid-19th century. By then, however, astronomers had long ceased to use it.

Where is the Oak? Too far south for most readers to see, its brightest star lies at −69° declination and was called Alpha (α) Roboris. This eventually became Beta (β) Argus in the old ship Argo; after Argo's division, it was renamed Beta (β) Carinae. The proper name of this star, Miaplacidus, seems to mix Arabic with Latin. The true meaning remains an etymological puzzle; it may mean "placid waters" but no one is certain.



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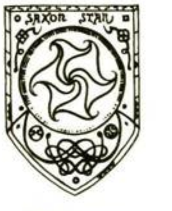

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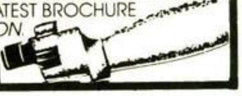

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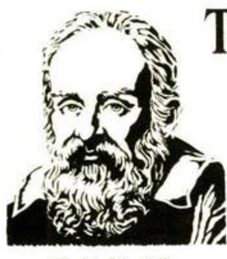

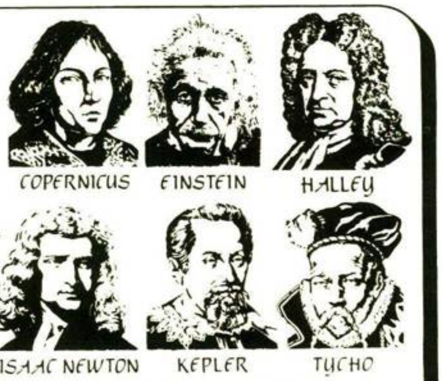

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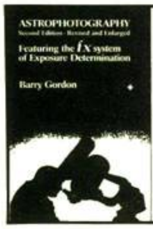
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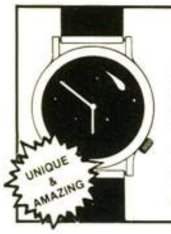

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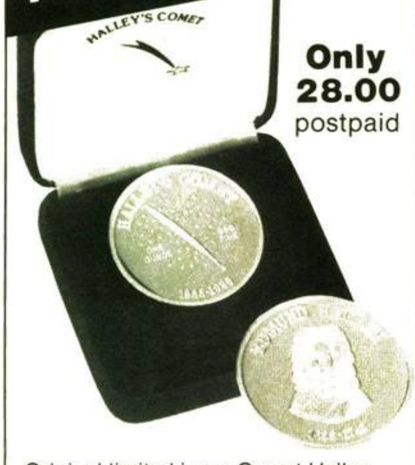

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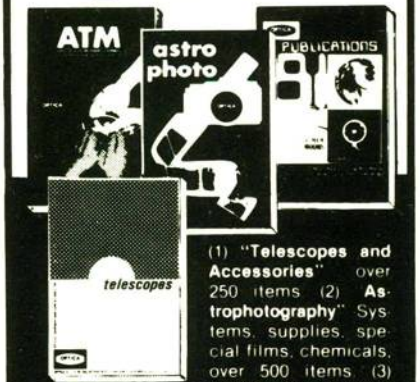

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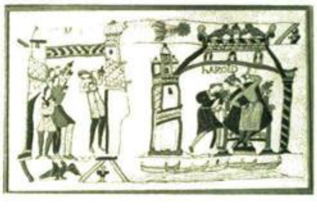

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←1066 A.D.
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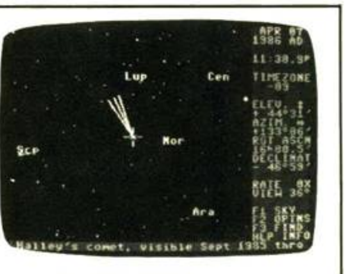

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ELEV.
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AZIM.
+133°06'
RGT ASCN
16h08.5'
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- 46°59'
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Equipment Atlas

How I Designed the Ultimate Astrographic Telescope

by Mike Simmons

For more than twenty years I've been working to achieve the best astrophotos possible. But this task is difficult, as you already know if you have tried your own hand at astrophotography. There are so many aspects to consider with a small- to medium-sized telescope, and everything counts. You have to consider film selection, special treatments such as hypersensitizing, processing the exposed film, enlarging the resulting negatives, finding a suitable observing site, the mechanical design and construction of the telescope mounting, getting proper focus, the guiding techniques you will employ, and so forth. The list is nearly endless. However, one fundamental requirement is an optical system capable of producing first-class negatives. As an optical designer, I've developed what I think is the ultimate optical system for moderate-field astrophotography — a design that I call the Simak.

But before I could even begin to design the ultimate astrographic telescope, I had to decide what attributes would be necessary for such an instrument. Designing a superb optical system would not be enough. I had to decide what I wanted to do with the telescope and then design one that had the right characteristics to do the job.

I began by compiling data on the most impressive deep-sky objects, those that I would ultimately be photographing with the ultimate astrograph. One thing that struck me very early on was that the ultimate astrograph would have to cover a field at least six moon diameters (3°) across to accommodate the best sky targets. The Andromeda Galaxy, the North America Nebula, the California Nebula, the complex of *nebulosities* surrounding Eta Carina, the Veil Nebula, and the Lagoon and Trifid Nebula complex all fit comfortably within a 3° circle.

Good photographs of deep-sky objects show details down to just a few seconds of arc across. This resolution limit is imposed by the seeing conditions at good observing sites. I decided that the ultimate astrograph had to be able to capture details down to 3 arcseconds across, and preferably half that.

At this point, film choice enters the picture. I opted for typical films used in astrophotography, such as Technical Pan, 103aF, and Fujichrome 100 and 400. To produce an image scale large enough that these films would be able to record such fine detail, the telescope had to have a focal length between 50 and 135 inches.

Interestingly enough, the designers of the 48-inch Palomar Schmidt camera went through a similar design process many years ago when they designed it. They settled on a focal length of 120 inches for this giant star camera. Because of ever-present atmospheric turbulence, increasing the focal length much beyond 120 inches would not result in significantly better pictures, you'd just get bigger star blobs.

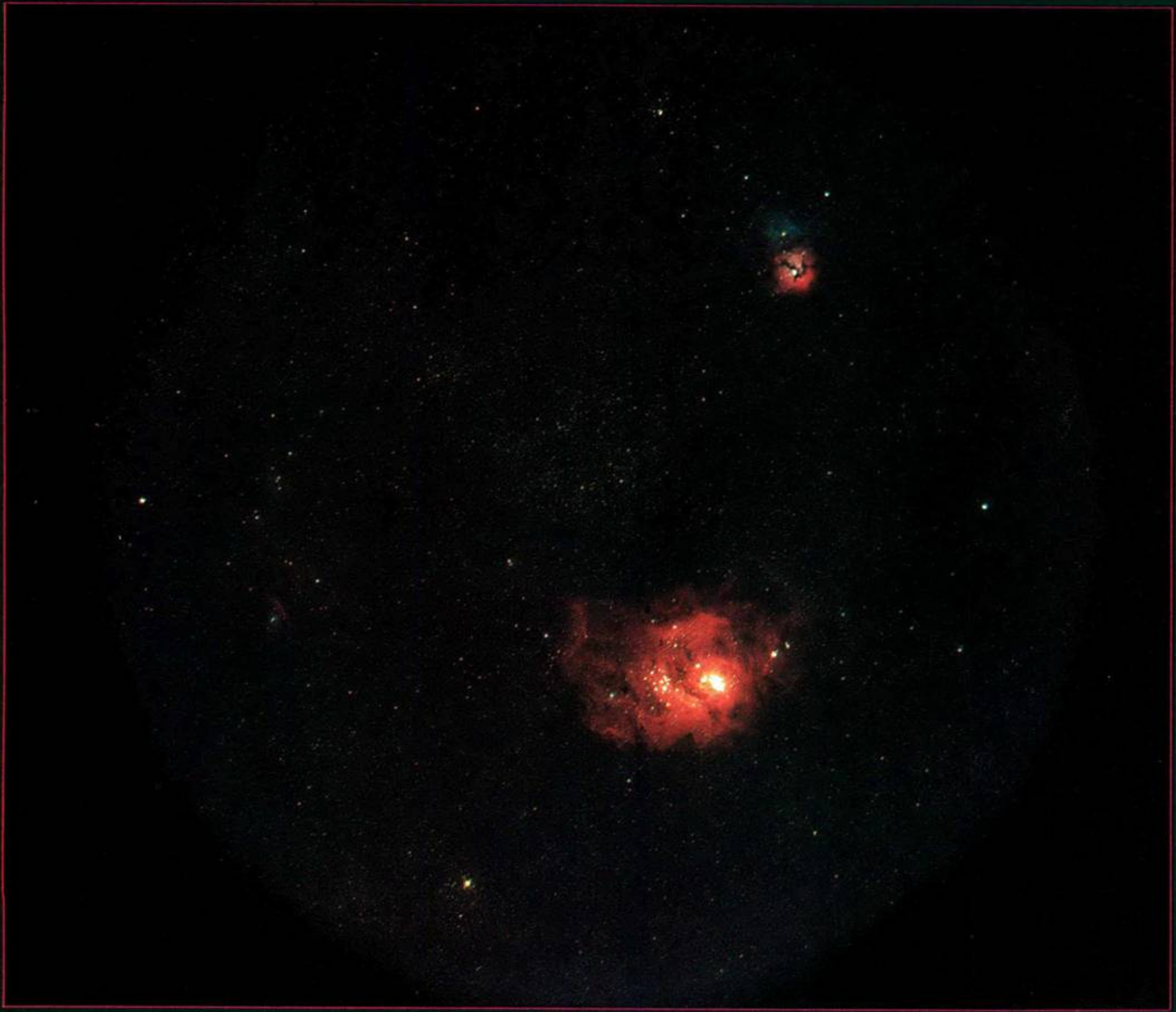
To record deep-sky objects with reasonably short exposures, an astrographic telescope requires a photographic speed between f/5 and f/8. Personally, I think that f/6.3 is the best focal ratio for a photovisual telescope. On modern hypered fine-grain films this is fast enough to record the sky background in an hour or so. And it just so happens that commercially available 40mm Erfle eyepieces give superb RFT views at this focal ratio. Within the range of focal lengths I had selected, the desired focal length and focal ratio imply an aperture between 8 and 20 inches.

My progress so far has defined a proposed telescope that would form an image of a 3° diameter section of sky that is between 2.6 and 7 inches diameter on the negative, depending on the focal length chosen. This means that even the biggest prints or display transparencies (21 to 56 inches in diameter) wouldn't require enlarging the negative more than eight times, which is just about the limit for making quality prints from ordinary fine-grain films. So far, so good.

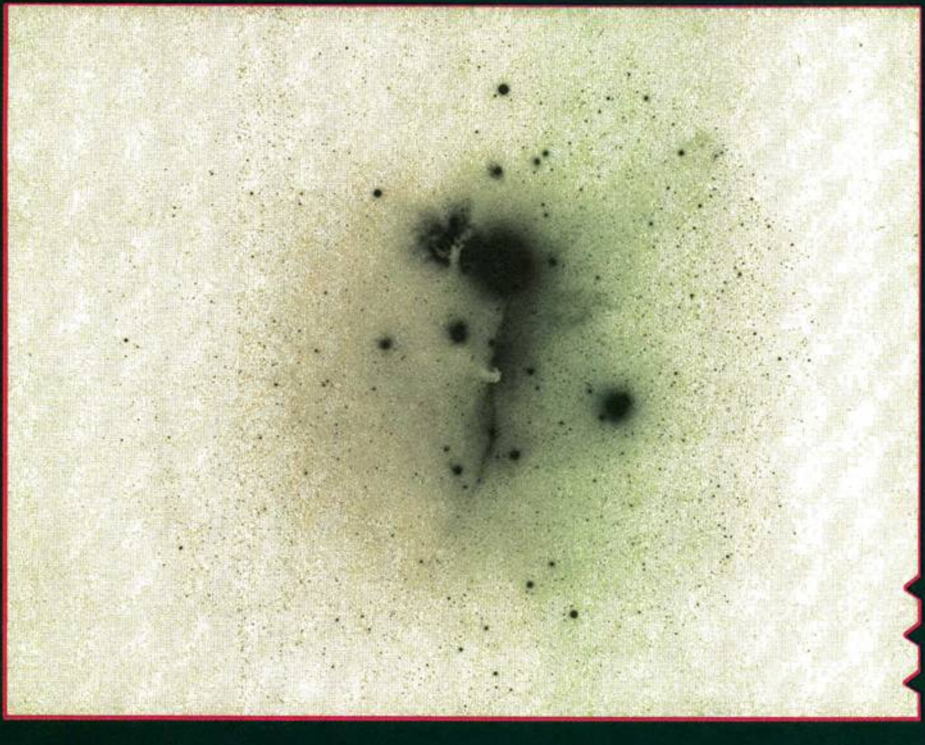
Having specified the design, I was ready to slip back into my role as optical designer. But there were still a few decisions to make. As it is difficult to bend film or plates to a curved focal surface, I decided that the ultimate astrographic telescope should have a flat focal surface. Furthermore, I wanted to avoid the inconvenience and mechanical problems of having the film inside the telescope tube, as Schmidt cameras do. These considerations dictated a telescope with

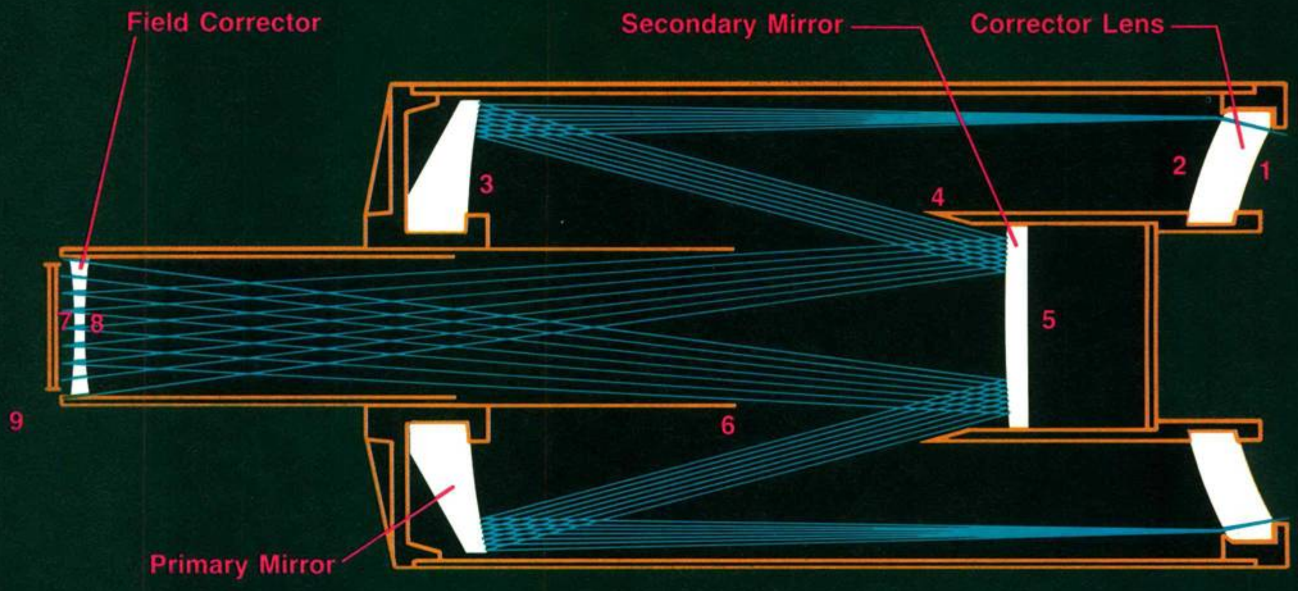
Overleaf left: This 90-minute exposure, taken with a 12-inch f/5 Astromak on hypersensitized Fuji R-100 film, shows the Rosette Nebula in all its glory. In both sharpness and limiting magnitude, the remarkable images on these two pages rival the best color shots made with the famed 1.2-meter Schmidt camera on Palomar Mountain. Photo by Jim Riffle.

Overleaf right: It didn't happen by chance — it was designed to be that way. Optical designer Mike Simmons set out to create a camera that could record the largest deep-sky objects in a single frame. The Andromeda Galaxy easily fits within the 3-degree field of a Simak. This 90-minute exposure was taken by Jim Riffle.



Above: The Lagoon Nebula lies at the center of a vast complex of nebulae. The 3-degree-wide field of the Simak design is essential for showing deep-sky objects in their settings. This photo is a 45-minute exposure on Fuji R-100 color slide film developed as a negative and printed on color photo paper. Right: One reason Simak pictures are so sharp is that Simak negatives are enormous. This negative, a 60-minute exposure of the region around the Horsehead Nebula on Kodak 103a-F film, is reproduced at its original scale. Photos by Jim Riffle with a 12-inch f/5 Astromak telescope.





Optical Specifications for a 10-inch f/6.3 Simak

Radii	Positions	Semidiameters
R1 = −10.736	P1 = 0.000	S1 = 5.500
R2 = −11.238	P2 = 0.850	S2 = 5.500
R3 = −43.000	P3 = 20.400	S3 = 5.500
R4 = baffle	P4 = 7.300	S4 = 2.500 o.d.<.05″ wall
R5 = −23.000	P5 = 6.100	S5 = 2.300
R6 = baffle	P6 = 13.500	S6 = 1.750 o.d.<.05″ wall
R7 = −13.000	P7 = 28.202	S7 = 2.000
R8 = 34.000	P8 = 28.402	S8 = 2.000
R9 = flat	P9 = 28.681	S9 = 1.800 (focal plane)

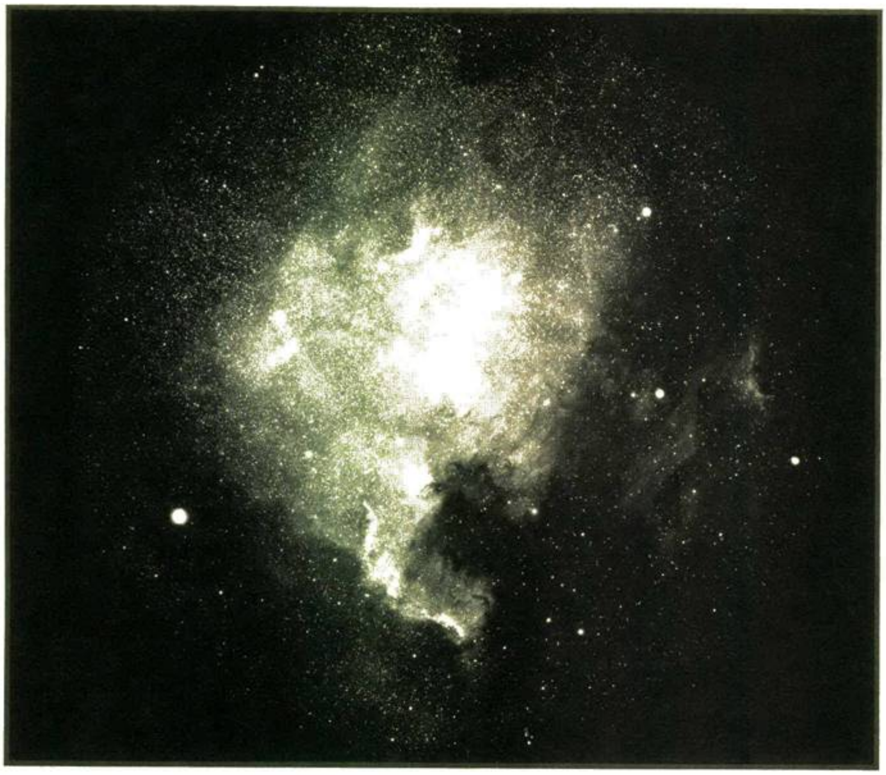
Above are optical specifications for a 10-inch Simak. Values of R represent the radii of curvature of the elements (negative means concave skyward) and those of P are the positions of the surfaces relative to the center of #1. Values of S are the semidiameters of the surfaces. Surfaces 1 and 2 are the front and rear of the Maksutov corrector, surface 3 is the primary mirror, and surface 5 is the secondary mirror. Surfaces 7 and 8 are the front and rear of the field-correcting lens just in front of focus. All measurements are given in inches.

Surfaces 4 and 6 are not optical surfaces but are the ends of baffle tubes intended to block out stray light. One baffle extends from the secondary mirror and the other from the central hole in the primary mirror. Although not shown, the system uses an 11.10 inch I.D. dew cap with the opening 18¼ inches forward of Surface 1 to block external light. Surface 9 is the focal plane where the film is placed.

The corrector and field lens are made from BK-7 glass; the mirrors from Pyrex, Zerodur, or an equivalent material. Surfaces are spherical except for #1, which must be slightly aspherized for optimum axial performance. The light loss at the edge of a 3° field is 20 percent, which is undetectable except by careful measurement. The field corrector may be removed for visual observing or for astrophotography with a 35mm camera; to compensate for field curvature, move the camera 0.005″ skyward after focusing the center of the field.

Mike Simmons is willing to advise amateur astronomers who are *seriously* interested in constructing a Simak telescope. You can write to him c/o AstroMedia (P.O. Box 92788, Milwaukee, WI 53202). The Astro Works Corporation (175 Piedra Loop, White Rock, NM 87544) manufactures a Simak design called the AstroMak™ that has an aperture of 12 inches and speed of f/5. The AstroMak offers both photographic and visual observing capabilities.

Astrophotos in this article were provided by Jim Riffle of Astro Works Corp. and were taken using a 12-inch f/5 AstroMak. Even though none of the photos were taken in the optimal seeing conditions typical of major observatories, you can see that their quality approaches the results of much larger telescopes at those sites.



Most telescopes with a 12-inch aperture can't record much of the North America Nebula in Cygnus. Most cameras that cover a field this large have a small aperture. The ultimate astrograph, by definition, should do both. This 70-minute exposure by Jim Riffle was shot on hypersensitized 103a-F film with a Wratten 22 filter to enhance the contrast of the nebula against the sky background.

a Cassegrain or Cassegrain-like optical system which forms an image behind the primary mirror.

If a telescope cannot produce high contrast images, deep-sky objects will suffer considerable loss of detail. To achieve high contrast, the optical system must have clean, well-polished, smooth, and zone-free optical surfaces. My own experiments have shown that dust, smears, poor polish, and zonal figure errors on mirrors cause much more loss of contrast than the same imperfections do on lenses. Indeed, according to optical designer James G. Baker, imperfections at reflective surfaces cause nearly 15 times more contrast loss than they do at refractive surfaces. I decided that the ultimate astrographic telescope would have to have a closed tube to keep its mirrors clean and spherical optical surfaces to facilitate making a smooth and zone-free optical figure.

The closed-tube requirement suggested a Maksutov- or Schmidt-like optical system. My desire for all-spherical optics ruled out designs having Schmidt correctors. In the end I chose a Maksutov-Cassegrain optical system as the basis for the Simak design. Here I became a pure optical designer. Using a computer program to trace light rays through the specifications for the optical system, I checked its performance, made changes in the specifications, and then checked it again. (Testing a "paper telescope" is much easier than testing a real telescope.) The program separates the various optical aberrations, so as I made successive changes I built up a detailed understanding of how the design works and thus could improve it further.

To flatten the field and remove an aberration called lateral color, I introduced a field corrector just in front of the film. Unlike many Maksutov-Cassegrain designs, the Simak's secondary mirror is not an aluminized spot on either the back or the front of the corrector lens. Separating the secondary gave me more "degrees of freedom" to improve the image quality over the entire field. After figuring out how to correct all the image aberrations and satisfying all the criteria I had set, the Simak was born.

However, there's more to top-notch astrocamera performance than optical design. Stray and scattered light must not reach the focal plane. Most telescope makers understand this and incorporate baffles and paint the interior surfaces of the tube assembly black to reduce scattered light. However, several other aspects of tube design can make a significant difference. For example, every telescope should have a combination light shield and dew cap extending at least 1.5 times the diameter of the tube. This need not add to the tube's length. It can be a separate part that you attach only when the telescope is in use.

The entrance aperture should be defined by a hard, smooth, perfectly round edge, like a machined metal knife-edge. The outside diameter of secondary or diagonal mirrors must also be hard, round, smooth, and accurately centered. Spider vanes used to support the secondary mirror cause extra scattering and diffraction; they should be eliminated by mounting the secondary on the corrector lens element or on an optical window.

Seemingly minor things matter, too. The rims of all lens elements should be blackened to prevent light from reflecting from their inner edges. Inside the tube, knife-edge baffles should be used to eliminate scattered light. Contrary to what you'd expect, baffles made from shiny black Plexiglas work better than metal painted flat black because the Plexiglas reflects unabsorbed light to the back of the previous baffle instead of scattering it in all directions inside the telescope. Knife-edge baffles are most effective if spaced so that you can't see the interior wall of the tube from its front end when the dew cap is in place.

The same characteristics that make the Simak design good for photography also produce exceptional visual performance for both deep-sky and planetary objects. My 12-inch f/5 Simak routinely shows Jupiter's four large moons as round disks, and when the seeing is good enough I can observe Encke's Division in Saturn's rings. Although my Simak has a 50 percent central obstruction, the contrast-enhancing techniques already described more than compensate for all the effects of the relatively large obscuration.

The design principles I used for the Simak apply to all types of telescopes. There is no reason why you cannot use these principles to design or improve existing telescopes. The astrophotographs shown in this article provide evidence that these principles do make a difference. On page 62, you'll find full optical specifications for a 10-inch f/6.3 Simak — one of my favorite designs. You may use this design if you want to build one for yourself or have one built for you by a custom optical shop.

There aren't a lot of Simaks around yet. Those of us who have them are still striving for better results. We're confident that when we start shooting longer exposures under better seeing conditions than we find in our own backyards, the astrophotos from our small instruments will be nearly indistinguishable from those taken by the giant Schmidt cameras on Palomar Mountain and Siding Spring, Australia. For those of you who do not have Simaks, I hope that the principles and techniques I've described will give you ideas for improving your current telescope, regardless of its type.

Mike Simmons invents optical and electronic systems and has also designed minicomputers, graphic terminals, computer controls for telescopes, and "all sorts of crazy things." He wrote his own optical design program and used it to design the Simak optical system.

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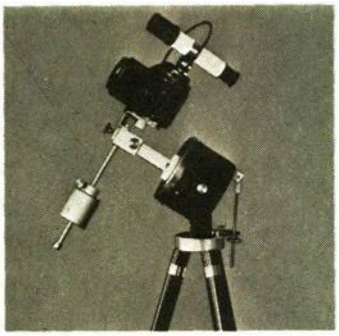

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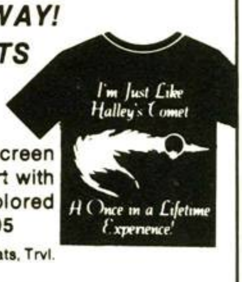
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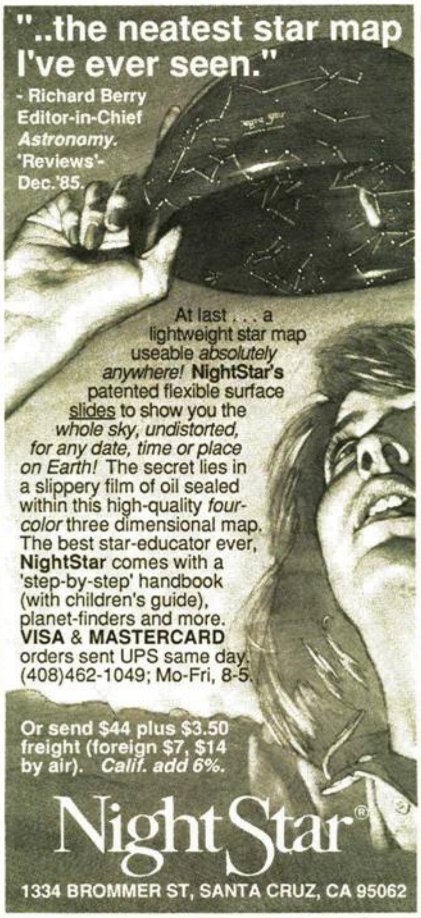

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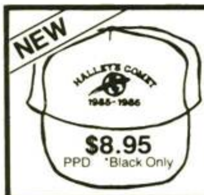

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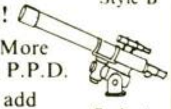

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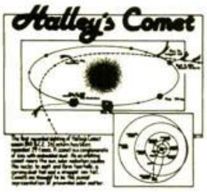

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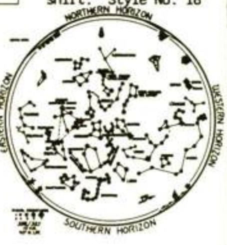

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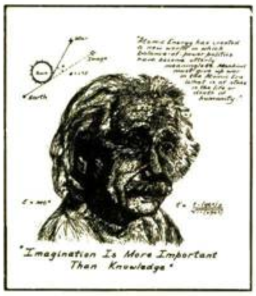
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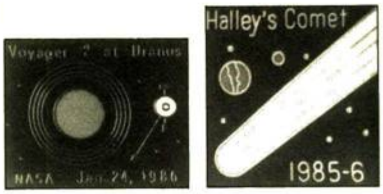

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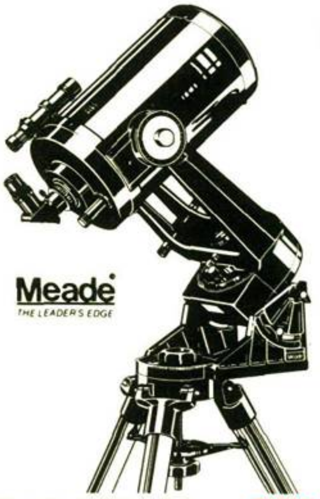

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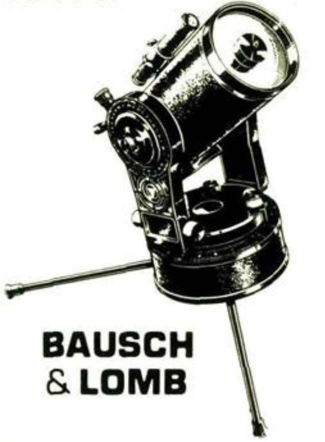

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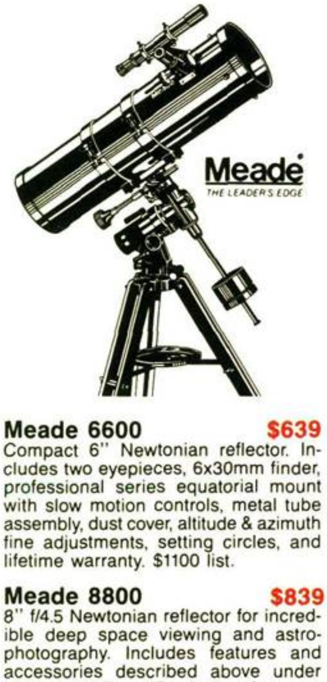

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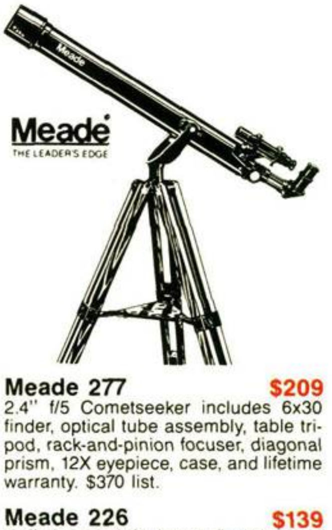

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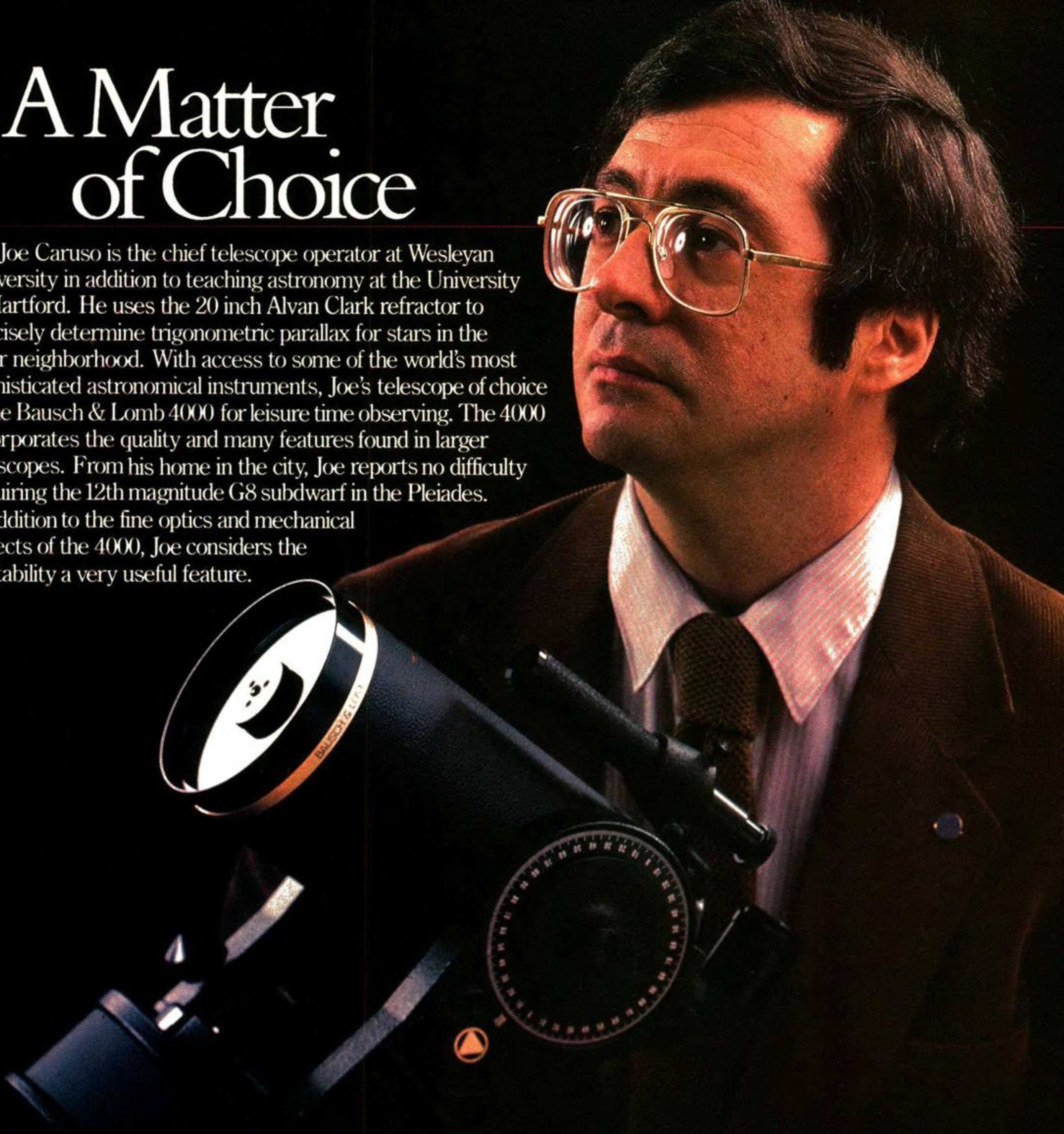

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ASTRONOMY

AstroNews

Challenger Disaster Halts Manned Flights

When Challenger exploded January 28, killing all seven crew members, the U.S. space program came to an unexpected halt. The disaster, the space program's worst in its quarter-century history, has forced NASA to conduct an unplanned re-evaluation of the Shuttle launch system. The delay is likely to disrupt crucial missions during this eminent year of space exploration (see "1986: A Busy Year for the Shuttle," ASTRONOMY, March 1986).

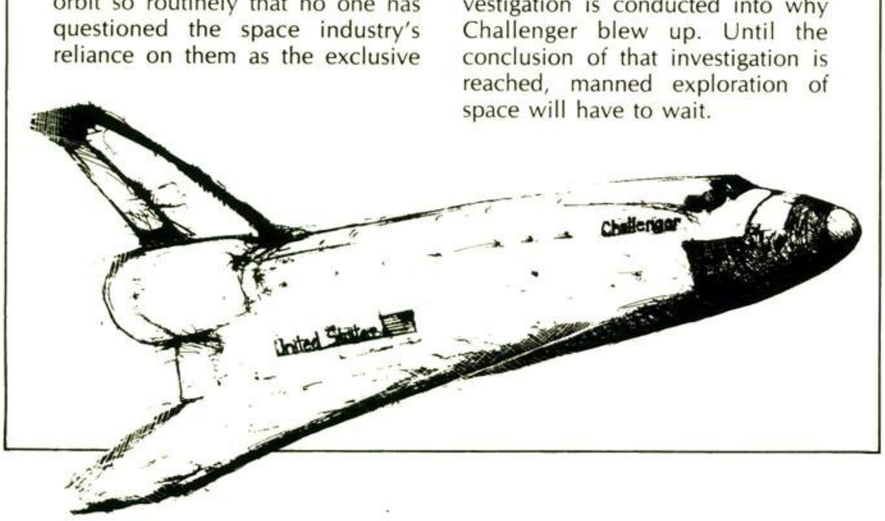
Fourteen Shuttle missions were planned for 1986, five of them using Challenger. Each mission was to carry a myriad of scientific experiments and payloads. NASA officials estimate that even a quick return to regular operations using the three remaining Shuttles would mean the delay of a number of projects. Marcia Smith, executive director of the National Commission on Space, was succinct when she said that the disaster "could not have come at a worse time."

Since April 1981, Shuttles have been making their way to and from orbit so routinely that no one has questioned the space industry's reliance on them as the exclusive vehicles for transporting commercial satellites and space probes. The big question now is: How will this dependency affect future space programs?

Three upcoming missions affected by the Challenger disaster are the Ulysses Sun probe and the Galileo mission to Jupiter, both scheduled for Shuttle flights in May, and the $1.2 billion Hubble Space Telescope. The Ulysses and Galileo missions have especially critical launch periods. If NASA does not resume launch preparations almost immediately, these missions will be postponed for at least a year.

All of this comes at a time when commercial companies and their insurers were expressing dismay at the Shuttle's erratic launch schedules and setbacks. Some space analysts are predicting that these companies may take their business elsewhere, namely to the European Space Agency and its Ariane rocket vehicle.

At press time, the only certainty is that scheduled Shuttle flights have been halted while a detailed investigation is conducted into why Challenger blew up. Until the conclusion of that investigation is reached, manned exploration of space will have to wait.



A Fifth Force of Nature?

Every high school physics student is familiar with the four basic forces governing the behavior of the universe: gravity, electromagnetism, the strong force (binding atomic nuclei), and the weak force (the culprit behind many types of radioactivity). All good physics students also know that there are four and only four such forces.

But last January a team of scientists, including physics professor Ephraim Fischbach of Purdue University and physicist S.H. Aronson of Brookhaven National Laboratory in New York, announced their discovery of a fifth fundamental force in the universe that acts upon all bodies.

To understand this mysterious fifth force, think back to the year 1589 when 25-year-old Galileo Galilei began teaching as Professor of Mathematics at the University of Pisa in Italy. It was then that Galileo, driven by the axiom "Ignorance of motion is ignorance of nature," performed his legendary experiment of dropping several objects of differing weights — perhaps a cannonball and a wooden ball or a cannonball and a musket ball — off the Leaning Tower of Pisa. The items hit the ground simultaneously. This famous experiment convinced the world that all objects, regardless of mass, fall at exactly the same speed.

The new findings dispute this long-standing principle of physics that has been accepted by virtually all physicists, including Newton and Einstein. Fischbach and Aronson report in *Physical Review Letters* that this fifth force, dubbed "hypercharge," is a relatively weak countergravitational force that only acts between objects within 600 feet of each other. The force repels protons and neutrons of one object from those of another. Its strength depends on an object's density, thus iron is affected far more than hydrogen. For example, if an iron cannonball and a wooden ball were simultaneously dropped inside a vacuum, the wooden

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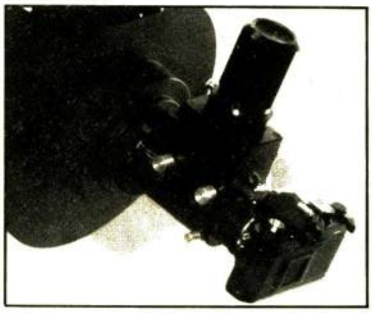

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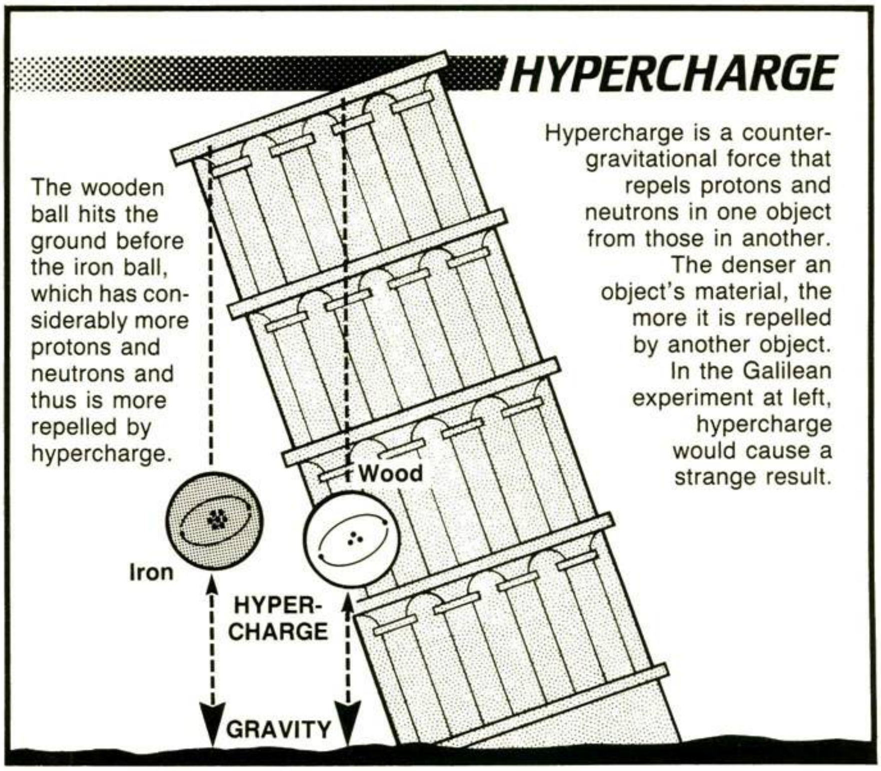


The wooden ball hits the ground before the iron ball, which has considerably more protons and neutrons and thus is more repelled by hypercharge.

Hypercharge is a counter-gravitational force that repels protons and neutrons in one object from those in another. The denser an object's material, the more it is repelled by another object. In the Galilean experiment at left, hypercharge would cause a strange result.

ball — although having less mass than the iron ball — would actually hit the ground *first* because it is less dense and not as affected by hypercharge.

Fischbach and Aronson found evidence for this fifth force when examining old data after obtaining strange results from their own gravity experiments. They searched through information compiled in 1922 by Hungarian scientist Baron Roland von Eotvos who had found discrepancies in the speeds at which various bodies fell. (von Eotvos, however, believed that these discrepancies were within the systematic error of his equipment.) The team reexamined von Eotvos' data and proposed that it showed evidence of hypercharge.

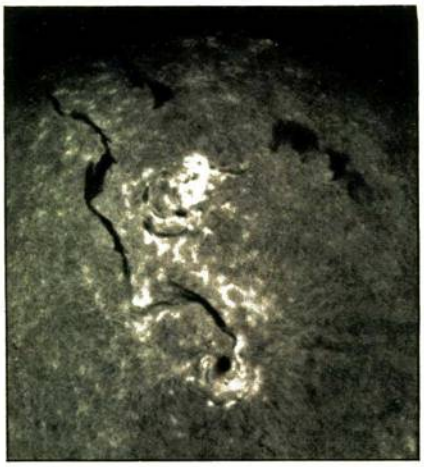
If hypercharge exists, it could have profound consequences for the universe as a whole. For example, there may well be "hyperphotons" — particles associated with hypercharge — that may be common enough in space to halt the universe's seemingly unstoppable expansion. If so; the universe could eventually fall back upon itself and recharge again — a seeming reinforcement of a closed universe. But many physicists remain skeptical, cautioning that much more data are needed before hypercharge can merit a place in the annals of science.

Sun's Brightness Decreasing

Since at least 1978, the Sun has undergone a steady downward trend in radiance. As reported in the January 24, 1986 issue of *Science*, three independent measurements made during the last five years support a decrease of nearly 0.02 percent per year in total solar output.

The first noted decrease was discovered by the Earth Radiation Budget (ERB) experiment onboard the NIMBUS 7 satellite, launched in 1978. According to results analyzed by John Hickey of the Eppley Laboratory in Rhode Island, the Sun is fading at a rate of 0.015 percent per year. This figure agrees with that obtained by Richard Wilson of the Jet Propulsion Laboratory. In December, Wilson reported that the Solar Maximum Mission satellite measured a decrease of 0.09 percent between February 1980 and early 1985.

Wilson also flew instruments on sounding rockets in 1980, 1983, and 1984. Claus Frohlic of the Physical Meteorology Observatory in Davos, Switzerland, independently made measurements by sending up instruments on high-altitude balloons in 1980 and 1983, and also on the same rocket flights used by Wilson in 1983 and 1984. Data from these seven flights show a decrease in solar brightness



of 0.016 percent per year as compared with the 0.015 to 0.019 percent figures that were obtained from the satellites.

Although a radiational decrease seems to be happening, its cause is unknown. The eleven-year sunspot cycle is a possible explanation. However, if data gathered by the 1978 ERB experiments are accurate, the decrease detected then was occurring at a time when sunspots were increasing toward their 1980 maximum.

A more plausible explanation might be found in the Sun's twenty-two year magnetic cycle. During this period, sunspots peak twice but their magnetic polarities reverse only once. While a cycle longer than twenty-two years seems unlikely, according to John Eddy of the National Center for Atmospheric Research in Colorado, ten years of such a decrease would mean a radiant reduction of 0.2 percent; even a ten-year decrease of 0.1 percent would be climatically significant. A 1 percent decrease in solar brightness could have caused the estimated one degree Centrigrade cooling associated with the "Little Ice Age" that gripped Europe from 1500 to 1850.

What happens to the irradiance factors during the next few years as sunspots reach minimum and then begin to peak again could determine whether or not the twenty-two year cycle is involved.

An intriguing idea was recently proposed by Martin Woodward of the Jet Propulsion Laboratory and Robert Noyes of the Harvard-Smithsonian Center for Astrophysics. Their work suggests that the Sun has expanded about 100 kilometers. If a correlation between size and irradiance can be substantiated, such an expansion could explain why the Sun is fading.

Missing Mass In the Asteroid Belt

Our solar system's primordial asteroid belt, located between the orbits of Mars and Jupiter, differs greatly from the one that we see today in one major respect: it had more mass. This is evident by the existence of asteroids the size of Ceres, which measures 1,003 kilometers across. Ceres would never have had time to condense, or accrete, in the less massive, higher-velocity medium that presently exists in the asteroid zone. The combined mass of all asteroids in the belt is currently estimated as 5 x 10^{24} grams, or about one thousandth the mass of Earth. But astronomers estimate that the primordial asteroid zone contained enough mass to form a planetary core the size of Earth. The question is, what happened to this mass?

According to a report in the December 12, 1985 issue of *Nature*, recent work by P. Farinella, P. Paolicchi, and V. Zappala offers two dynamical models that could have worked to deplete mass from the asteroid zone. One model proposes that there was a continual, gradual loss of mass

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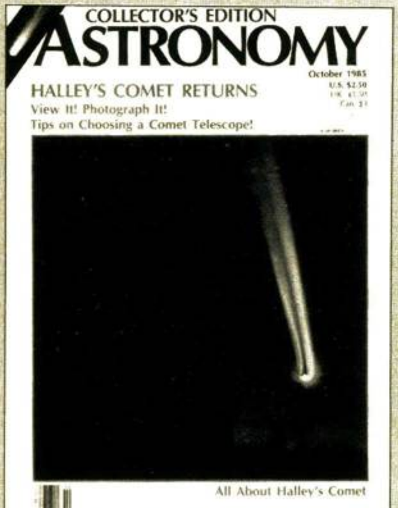

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from the asteroid zone; the other model suggests that the main mass was lost during the zone's early history.

In the first approach, mass in the form of asteroid dust from collisions might have been gradually carried away by radiation or the solar wind. In a sense, mass would have "eroded" from the asteroid zone until it reached its present amount.

The second approach is more complex and involves the "stirring up" of asteroid particles by an outside body — the likely candidate being a nascent Jupiter. Here, the orbital velocities of asteroid particles would be significantly increased, resulting in impacts and fragmentation rather than a leisurely accretion process.

There are several observational constraints worth considering in light of these two processes. Vesta, the fourth largest asteroid, has a thick basaltic crust some 60 kilometers thick. For such a crust to have survived this long means that it could not have been subjected to shattering by many primordial bodies during the early stages of its formation.

A second constraint is that the observed number of "families" of asteroids — those having similar orbits — is too high to support a collision-dominant theory. Evidence that groups of asteroids still exist today, undisrupted, indicates collisions were, and still are, rare.

Another restricting factor is that one third of the large-body asteroids (in the 200- to 300-kilometer range) have elongated shapes. If these shapes resulted from collisions, there should have been five times as many asteroids greater than 65 kilometers in diameter in the primordial population.

Although astronomers can now choose between two collisional models, the reason why the mass of the primordial asteroid zone was five times more than what it is now requires further investigation.

U.S. Forests Offer Good Halley Viewing

The U.S. Forest Service has designated a number of "Halley's Comet Observation Points" at forests throughout the eastern United States. These locations offer Halley watchers dark sites for viewing during this, the last month of observing the comet at its brightest.

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Additional information is available through your local forestry office or by phoning the Eastern Regional Office in Milwaukee, Wisconsin, (414) 291-3693.

ASTRONOMY
AstroCalendar

April 4-12
Halley's Comet Festival (films, children's programs, "second timers" picnic), North Bend and Pipestem State Parks, West Virginia. Contact: Joe Woodfield, Halley's Comet Coordinator, Bluestone State Park, Hinton, WV 25951. Phone toll-free (800) CALL-WVA.

April 5
Halley's Comet Watch, sponsored by the Arkansas Oklahoma Astronomical Society, Ben Geren Regional Park, Fort Smith, Arkansas. Contact: Larry Kennedy, Route 3, Box 421-Y, Pocola, OK 74902. Phone (918) 436-2204 evenings.

April 11
International Halley Day of Harmony. Contact: James B. Harris, Jr., Florida Space Week Committee, P.O. Box 291, Sharpes, FL 32959. Phone: (305) 632-9139.

April 12
40th Annual Convention of the North Central Region of the Astronomical League, sponsored by the Popular Astronomoy Club, Augustana College, Rock Island, Illinois. Contact: Paul Castle, 1986 NCRAL Convention Chairman, 2535 45th St., Rock Island, IL 61201.

April 19
Astronomy Day. Contact: Gary Tomlinson, Astronomy Day Coordinator, Astronomy League, Chaffee Planetarium, 54 Jefferson S.E., Grand Rapids, MI 49503. Phone (616) 456-3985.

April 19
Astronomy Day Celebration and Star Party, sponsored by the Northwest Suburban Astronomers, Hoffman Estates, Illinois. Contact: John Conneely, 814 Gettysburg, Arlington Heights, IL 60004. Phone (312) 253-4735.

April 23-26
Middle Atlantic Planetarium Society Annual Spring Meeting, Wheeling, West Virginia. Contact: Steve Mitch, Benedum Natural Science Theater, Oglebay, Wheeling, WV 26003.

May 5-10
Texas Star Party, Prude Ranch, Fort Davis, Texas. Contact: Carol Rodgers, 128 N. Commerce, Burleson, TX 76028.

May 9-10
Microcomputers in Physics and Astronomy, Valdosta State College, Valdosta, Georgia. Contact: Dr. Dennis Marks, Dept. of Physics, Valdosta State College, Valdosta, GA 31698.

May 16-18
Annual Meeting and Conference of the Royal Astronomical Society of New Zealand, Palmerston North, New Zealand. Contact: Noel Munford, President, Palmerston North Astronomical Society Inc., Centennial Observatory, Anzac Park, P.O. Box 398, Palmerston North, New Zealand.

May 22-25
Riverside Telescope Maker's Conference, Camp Oaks, Big Bear, California. Contact: Cliff Holmes, 8642 Wells Ave., Riverside, CA 92503. Phone (714) 689-6893.

May 23-26
Fifth Annual Space Development Conference, Seattle, Washington. Contact: 1986 Space Development Conference, Dept. C3, P.O. Box 30869, Greenwood Post Office, Seattle, WA 98103.

June 19-21
IAPPP Symposium on Photoelectric Photometry, Mercyhurst College, Erie, Pennsylvania. Contact: Robert C. Reisenweber, Rolling Ridge Observatory, 3621 Ridge Parkway, Erie, PA 16510. Phone (814) 899-2560.

June 22-26
168th Meeting of the American Astronomical Society (professional meeting), sponsored by Iowa State University, Ames, Iowa. Contact: AAS, 1816 Jefferson Pl., N.W., Washington, DC 20036.

June 27-30
Royal Astronomical Society of Canada General Assembly, Winnipeg, Manitoba, Canada. Contact: Lorence Mlodzinski, Registration Committee, R.A.S.C. General Assembly 1986, P.O. Box 174, St. James Post Office, Winnipeg, Manitoba, Canada R3J 3R4.

June 29-July 4
International Planetarium Society Eighth Biennial Conference, Tucson, Arizona. Contact: IPS Conference Committee, Flandrau Planetarium, University of Arizona, Tucson, AZ 85721. Phone (602) 621-4515.

July 12-17
98th Annual Meeting of the Astronomical Society of the Pacific, University of Colorado, Boulder, Colorado. Contact: A.S.P., 1290 24th Ave., San Francisco, CA 94122. Phone (415) 661-8660.

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ASTRONOMY
Reviews

Mankind's Comet
Guy Ottewell and Fred Schaaf
193 pages, softcover, $22
Furman University (1985)
[Publisher's address: Furman University, Greenville, SC 29613]

Wow! This is the best Halley book yet! *Mankind's Comet* is a super reference for all backyard astronomers who want to remember Comet Halley. It is a big (15" x 11") floppy album chock-full of Halley data including elaborate charts and maps drawn in a down home, sketchy style and background information on observing Halley during the 1986 apparition.

Unfortunately this book appeared late in December 1985, leaving too little time for proper marketing of a superior product. Probably too few will have heard of it before the comet becomes a memory for another seventy-six years.

The book begins by proclaiming that Halley is something everyone can enjoy. In a section titled "The Unfolding," the authors look back on past ideas about comets during Mesopotamian, Chinese, Greek, Roman, and Renaissance eras. From there, readers are introduced to Edmond Halley — including a gruesomely detailed account of his name's correct pronunciation — and his relationship with Isaac Newton. The historical dialogue continues with brief accounts of the 1759, 1835, and 1910 apparitions and what was happening in science and society between those periods.

The "Strobe-light" section recounts the observational highlights of each apparition since 1404 B.C. and probable reasons why early showings of Halley weren't recorded. For example, in 1404 B.C. the comet "must have passed very close to the south [pole], appearing to plunge almost through the nether pole of the sky. It may well then have been seen by the hunter-gatherers of the Cape, Tierra del Fuego, and Tasmania, but not by the literate civilizations along the Nile, the Tigris and Euphrates, Indus and Ganges, Yangtze and Yellow River."

The first full description of Halley's appearance comes from Chinese observations during the apparition of 12 B.C.: "On a *hsin-wei* day in the 7th month of the 1st month of the Yuan-Yen reign-period [August 26, 12 B.C.], a sparkling star was seen at the Tung-Ching, treading on Wu-Chu-Hou [Tau Geminorum]." There are dozens of such descriptions in the book, all equally fascinating to read.

The following section, "A Typology of the Halley Visits," includes some really interesting stuff. One page contains the tracks — apparent paths on the sky — for all forty-eight Halley visits. Following this is information on comets in general, a glossary of cometary terms, and an overview of the nature of Halley's Comet.

"Re-entry on the Stage" picks up the story again on October 16, 1982, when two Caltech astronomers recovered Halley's feeble glow. Included here is information on the International Halley Watch, spacecraft scheduled to rendezvous with Halley, and author Schaaf's "Dark Skies for Comet Halley" project, which aims to reduce manmade lighting for the comet's appearance. Also found here is a chronological calendar of important dates during the current apparition.

"The Future" looks ahead to a time when very few of us will be around to see Halley's Comet again. The 2061 apparition will be significantly better than the current one since Halley will be far brighter and closer to Earth; it will also be higher in the sky for Northern Hemisphere viewers at that time. But the really odd twist is that Halley may never actually leave us this time: the Space Telescope might very well be capable of tracking Halley throughout its entire orbit, even when it reaches aphelion in 2023.

The remainder of *Mankind's Comet* consists of forty-eight atlas charts showing Halley's apparent path in the sky for each apparition between 1404 B.C. and A.D. 2134. These are fascinating to page through. The sky background — stars, constellation boundaries and names, and the ecliptic and galactic equator — appears in subtle gray while the comet is printed in black. Halley's tail is plotted as a series of tiny dots, creating a three-dimensional feel.

If this book had been published earlier, many people might have picked it as one of the best information sources on Comet Halley. Yet it's quite understandable how a volume containing so much information took a long time to produce. In any case, I highly recommend this book for anyone who either enjoys reading about Halley or who wants a meaningful- and information-packed souvenir of the Grand Old Comet's latest visit to planet Earth. *David J. Eicher.*

Astronomical Objects for Southern Telescopes
E.J. Hartung
238 pages, paperback, $19
Cambridge University Press (1985)

Because of the almost constantly changing state of information on clusters, nebulae, and galaxies, many amateur observing guidebooks are outdated by the time they appear in print. This is unavoidable because the information astronomers produce about deep-sky objects is ever growing and, little by little, our knowledge of these objects is constantly being refined.

This fact is the downfall of observing guides that provide only data — numbers such as magnitudes, diameters, and position angles. All too many guidebooks compound the problem by quoting often inaccurate descriptions of objects made by observers over a century ago.

A refreshing standout in the crowd of deep-sky observer's guidebooks is *Astronomical Objects for Southern Telescopes*, which was first published in hardcover nearly twenty years ago and is now available in paperback. Australian observer E.J. Hartung compiled this book from observations he made from his observatory at Lavender Farm, Victoria, Australia, during the 1960s. This reprint is unaltered from Hartung's first edition. So the question that naturally follows is: What makes a twenty-year-old observing book valuable today, considering the fast-changing world of astronomical data?

Hartung, who died in 1979, was a meticulous, articulate observer with the ability to accurately describe what he saw in the eyepiece of his 12-inch telescope. (He also used 6-inch, 4-inch, and 3-inch scopes.) The bulk of the book consists of 1,017 short paragraphs describing in detail how each object appeared to Hartung's sharp eye. Because he was a careful observer and recorder, the descriptions jibe well with each other. Consequently, they form an invaluable guide for observing deep-sky objects south of +50° declination with a moderate size telescope. And by using his own methodical observations, which are not based on other people's data, he avoided the out-of-date syndrome as much as possible.

An excerpt discussing the globular NGC-6496 in Corona Australis reads: "This globular cluster belongs to the most open type of these objects; 30 cm discloses a faint roundish haze about 2′ across without central condensation. Some faint stars may be seen in it but these may be field stars as the surrounding region is well shown. The cluster is shown by 10.5 cm as a dim hazy spot; interstellar absorption is rated here as m. 1.7 and R is estimated as 6,000 pc."

The concise nature of his observations packs an incredible amount of information into the book's 238 pages. It is truly a handbook-reference guide to keep beside your telescope for checking an object here or there. And its use isn't limited to Southern Hemisphere observers: many of the objects discussed are routinely visible from Europe and North America.

Hartung's work also contains introductory chapters on getting acquainted with observing and the astrophysical nature of deep-sky objects. Here the reader should beware because much has changed in our understanding of galaxies and nebulae since 1968, and observing techniques have been altered drastically by the Dobsonian revolution. The publisher might well have revised at least the astrophysical sections. There are a few other problems such as a couple of backward printed photographs, but the observational text seems to be as near to flawless as possible. The book contains enough good visual descriptions to make it well worth the price.

While not a suitable text on either observing techniques or the nature of galaxies, *Astronomical Objects for Southern Telescopes* is an invaluable reference work because of its observational descriptions, the pattern of which should be followed by deep-sky observers everywhere. *David J. Eicher.*

The Mystery of Comets
Fred L. Whipple
267 pages, hardcover, $24.95; softcover, $12.50
Smithsonian Institution Press (1985)

Dean of cometary astronomers, Fred Whipple has now written a popular-level book on comets. Although it is being released during the height of the Comet Halley craziness, this book has only two chapters devoted specifically to Halley's Comet and they are historical in content.

The Mystery of Comets is a general book on the present-day understanding of comets. Whipple takes the reader on a personally narrated trip through the history of cometary studies. I was pleased and intrigued by the thorough discussion of the many theories about comets from ancient times and from many cultures.

Whipple describes how the work of Renaissance scientists like Copernicus, Tycho, Kepler, and Galileo emerged as Aristotelian ideas on comets slowly lost their grasp. Edmond Halley's work on comets receives a chapter of its own, which is followed by a slight sidetrack in the next chapter with descriptions of Halley's Comet through history. The returns of 1758-59, 1835-36, and 1910 are emphasized and the chapter closes with short descriptions of the returns from 240 B.C. to A.D. 2061 (Curiously, he skips the returns of A.D. 912 and 989.)

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Whipple continues his historical account of cometary investigation with a discussion of the great comet hunters and the many discoveries and advances of the 19th century. The web of ideas that Whipple spins is very useful and complete — and frustrating! I found myself wanting to jump ahead when he briefly describes a new concept and then refers us to a forthcoming chapter for a more complete discussion.

The last half of the book concentrates on developments in comet science since the late 1880s, including a personal account of how Whipple conceived the currently accepted model of comets — the dirty snowball. We learn about the snowball's rotation and composition, possible landscapes on comet nuclei, and the formation of comets. The final chapter discusses spacecraft missions to comets.

The book has a few typographical errors. On page 189, CO+ should read CO^{2+}; on page 257 the Dr. Remeis Observatory should read the Remey Observatory; on page 258, P/Drommelin should read P/Crommelin; and on page 259, the Draconid meteor storm occurred in 1946, not 1936.

The text contradicts itself slightly regarding the cratering of the ocean floor by impacts, including the postulated Cretaceous-Tertiary event. Also, the description of the leadership of the International Halley Watch is incomplete.

The book is well illustrated and includes color plates. The last of the plates is of an obsolete model of the Giotto spacecraft. On page 139, photos "a" and "b" of Comet Halley should be interchanged to match the caption. On page 197, the top figure puts colder temperatures higher on the graph, which is confusing, and the bottom figure is virtually uninterpretable. On page 261, the trajectory figure for the ISEE 3 mission (renamed ICE) shows only a small portion of its journey from Earth's gravitational control to its Comet Giacobini-Zinner flyby trajectory.

But don't take these criticisms too strongly — I heartily recommend this book to everyone interested in comets, be they armchair, amateur, student, or professional astronomer. The book combines a history of cometary studies with up-to-date knowledge about these creatures from the cosmic zoo in a descriptive and sometimes chatty style. This book by Mr. Comet, as Fred Whipple is known, is a must for everyone interested in comets. *Stephen J. Edberg.*

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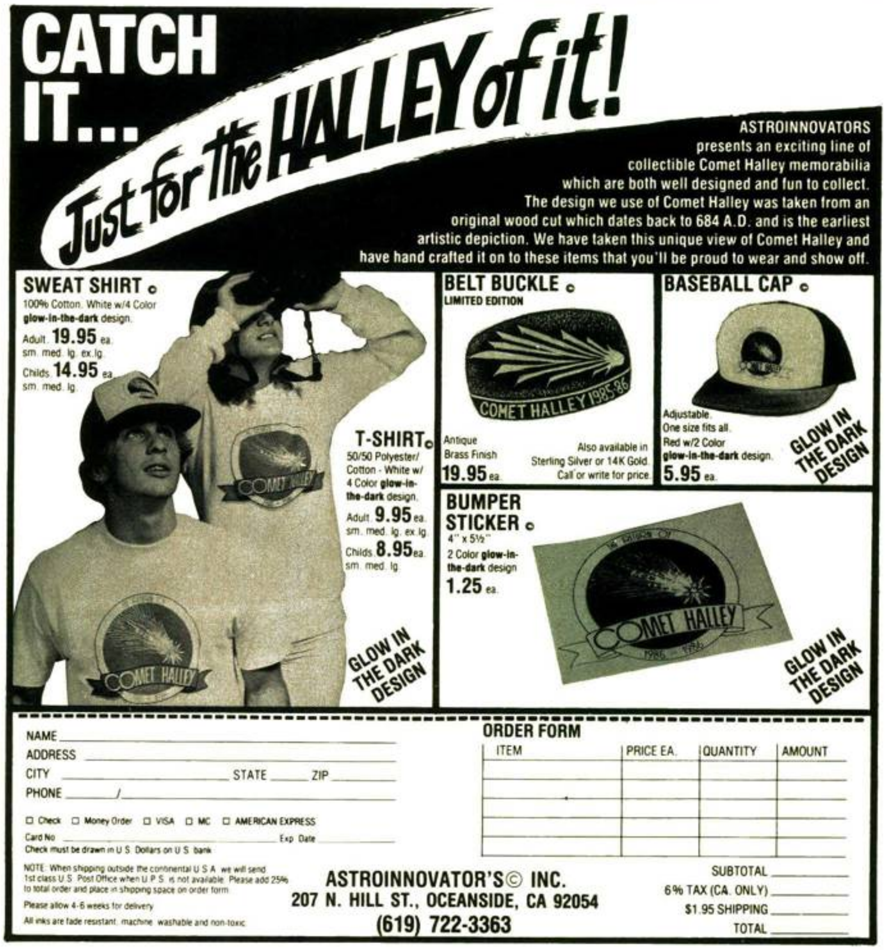

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I've found this eyepiece a pleasure to use. My only disappointment is that it has shown me just how bad my clock drive is. But then, this is one of those things it's better to know than not to know! *Michael A. Covington.*

Birth and Infancy of Stars
Robert Lucas, Alain Omont, and Raymond Stora, eds.
846 pages, hardcover, $159.25
North-Holland (1985)

This is the proceedings from a technical conference on starbirth held in 1983 at the Les Houches Summer School in Switzerland. The topics include star formation on galactic scales, protostars and their behavior, evolution of interstellar grains, and properties of molecular clouds. The contributors include Bruce Elmegreen, George Herbig, and Joseph Silk.

Mass Loss From Red Giants
Mark Morris and Ben Zuckerman, eds.
320 pages, hardcover, $49
Reidel (1985)

The proceedings from a conference held at UCLA late in 1984, *Mass Loss* contains such papers as "Optical Spectroscopy of Red Giants" by Leo Goldberg, "Bipolar Nebulae and Mass Loss From Red Giant Stars" by Martin Cohen, and "Masses of White Dwarfs and Other Remnants" by Virginia Trimble.

New Aspects of Galaxy Photometry
H. Araki, J. Ehlers, K. Hepp, R. Kippenhahn, H.A. Weidenmuller, and J. Zittartz, eds.
350 pages, softcover, $23.70
Springer-Verlag (1985)

New Aspects of Galaxy Photometry contains the proceedings from the eighth regional International Astronomical Union meeting held at Toulouse, France, in 1984. The work includes papers such as "Food for the Photometrists — Faint Galaxies Revealed" by David F. Malin, "Photographic Photometry of 16,000 Galaxies on ESO Blue and Red Survey Plates" by A. Lauberts and E.A. Valentijn, and "A Compilation of UBVRI Photometry for Galaxies in the ESO/Uppsala Catalogue" by A. Lauberts and Elaine Sadler.

Interacting Binary Stars
J.E. Pringle and R.A. Wade, eds.
220 pages, hardcover, $49.50
Cambridge University Press (1985)

This volume is an in-depth technical overview of interacting binaries that includes information on astronomical nomenclature and the effects of stellar evolution on close binaries, x-ray binaries, contact binaries, and cataclysmic variables.

The Crab Nebula and Related Supernova Remnants
Minas C. Kafatos and Richard B.C. Henry, eds.
285 pages, hardcover, $39.50
Cambridge University Press (1985)

This volume is a compilation of the proceedings from a seminar held at George Mason University in Fairfax, Virginia, in 1984. The papers covered include the chemical composition of M-1, models for its radiation, the Crab's evolutionary history, the progenitor star, and x-ray and radio observations of other Crab-like supernova remnants.

Kodak Ektachrome 100 Color Slide Film
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This film replaces Kodak's old Ektachrome 64, which has been discontinued. Intended for general color photography, Ektachrome 100 gives excellent color rendition, relatively high contrast, and virtually no visible grain. The colors are noticeably less blue than the other Ektachromes.

Ektachrome 100 looks very promising for lunar and planetary photography and for slide duplication. Duplicates made on Ektachrome 100 have considerably more contrast than the original slides — an advantage when you want to bring out faint nebulosity in starfields.

Ektachrome 100 is too slow for most kinds of deep-sky photography, although 15-minute exposures of starfields through an f/2.8 or faster lens can give pleasing results. The sky background tends to be brownish, almost black, rather than blue as with the faster Ektachromes. The film shows star colors vividly. In one of my test pictures, V Aquilae (spectral type N) was bright orange.

A special advantage of Ektachrome 100 is that Kodak has selected it for mass marketing; it is often available at supermarkets and drugstores at discounted prices. *Michael A. Covington.*

Stargazing
Patrick Moore
176 pages, hardcover, $19.95
Barron's (1985)

Subtitled "Astronomy Without a Telescope," this work introduces new stargazers to the constellations, star legends, the Sun, the planets, the Moon, aurorae, meteors, and other details of the sky as seen from both the Northern and Southern Hemispheres.

Kodak Ektachrome P800/1600 Color Slide Film
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These are two of the newest high-speed color slide films. Ektachrome P800/1600 is a special version of Ektachrome 400 designed for push-processing. With normal E-6 development its speed is ISO 400, but extending the first development time raises the speed to 800, 1600, or even 3200. (Kodak processing laboratories will push it to 800 or 1600 upon request.) Focal ISO 400 color slide film is made by 3M and marketed nationally by K mart.

In long exposures, the Focal film suffered much less reciprocity failure than the Ektachrome did. As a test, I made two identical five-minute exposures of a starfield, one on Focal film (processed normally) and one on Ektachrome P800/1600 (push-processed to ISO 1600). To my surprise the Focal film showed stars about one magnitude fainter as well as more detail in the Milky Way. The difference would have been even greater if the two films had been given identical processing. In addition, the Focal film had better color; my Ektachrome slides had a strong bluish cast.

The situation is different in pictorial photography. With exposures of less than one second both films deliver their full-rated speed. In addition to being faster, Ektachrome P800/1600 delivers higher contrast and more saturated colors. With identical processing, the two films are about equally grainy; push-processing the Ektachrome increases the grain noticeably. Both films are too coarse-grained for lunar and planetary photography.

3M's ISO 1000 color slide film has also been reported to be good for long exposures, though it is considerably grainier than the Focal ISO 400 product. *Michael A. Covington.*

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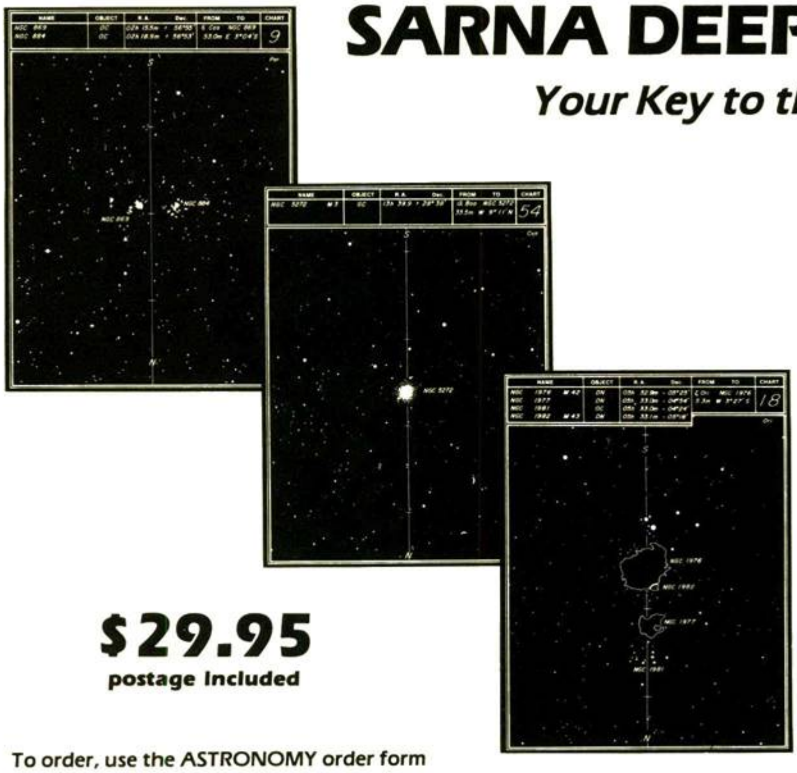

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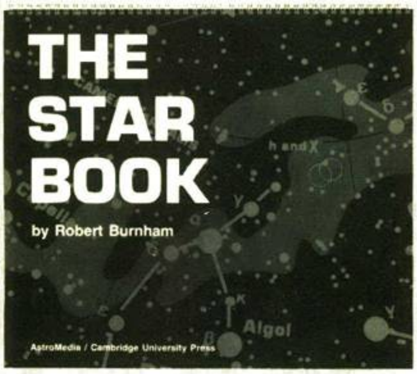

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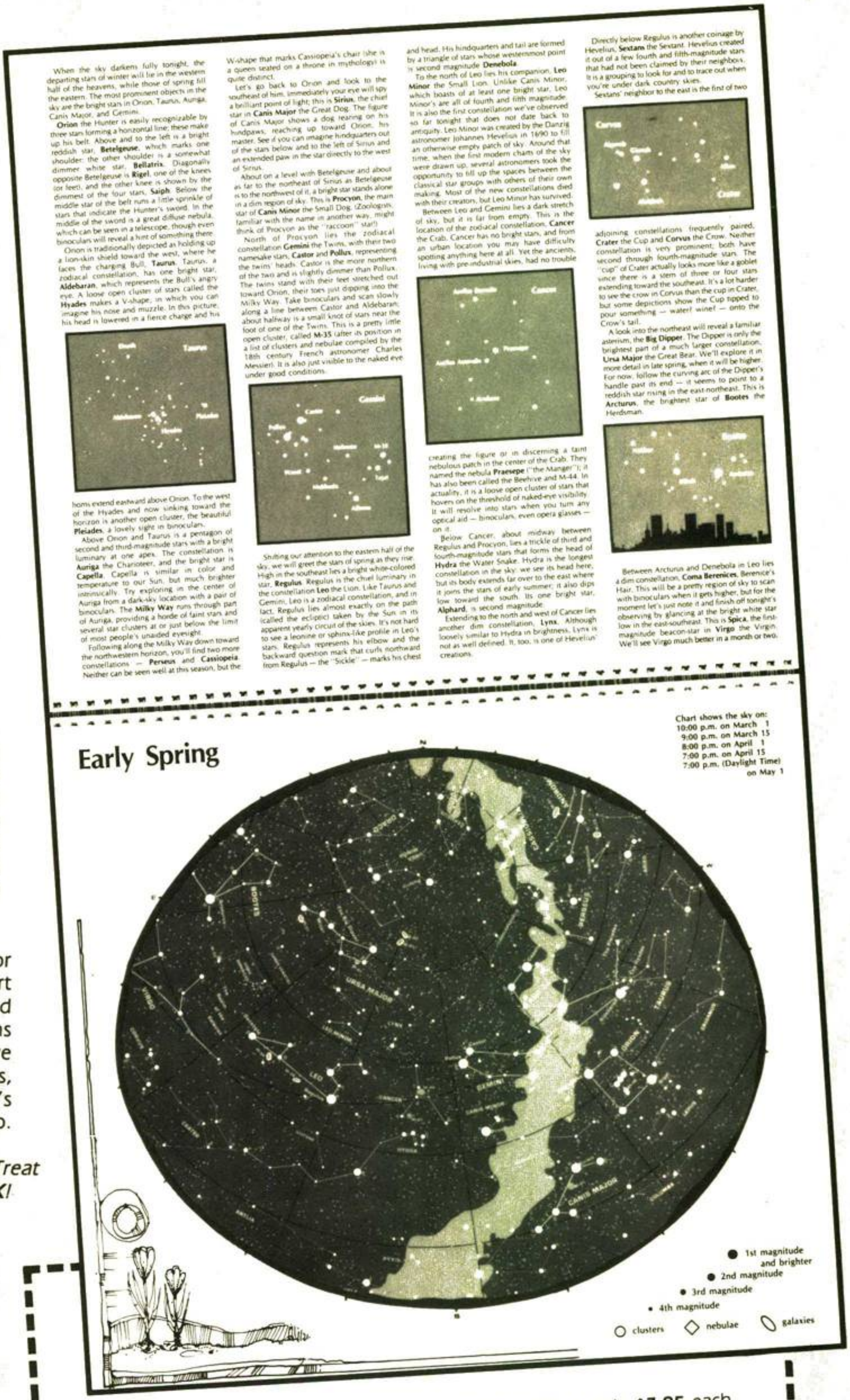

When the sky darkens fully tonight, the departing stars of winter will lie in the western half of the heavens, while those of spring fill the eastern. The most prominent objects in the sky are the bright stars in Orion, Taurus, Auriga, Canis Major, and Gemini.

Orion the Hunter is easily recognizable by three stars forming a horizontal line; these make up his belt. Above and to the left is a bright reddish star, **Betelgeuse**, which marks one shoulder; the other shoulder is a somewhat dimmer white star, **Bellatrix**. Diagonally opposite Betelgeuse is **Rigel**, one of the knees (or feet), and the other knee is shown by the dimmest of the four stars, **Saiph**. Below the middle star of the belt runs a little sprinkle of stars that indicate the Hunter's sword. In the middle of the sword is a great diffuse nebula, which can be seen in a telescope, though even binoculars will reveal a hint of something there.

Orion is traditionally depicted as holding up a lion-skin shield toward the west, where he faces the charging Bull, **Taurus**. Taurus, a zodiacal constellation, has one bright star, **Aldebaran**, which represents the Bull's angry eye. A loose open cluster of stars called the **Hyades** makes a V-shape, in which you can imagine his nose and muzzle. In this picture, his head is lowered in a fierce charge and his horns extend eastward above Orion. To the west of the Hyades and now sinking toward the horizon is another open cluster, the beautiful **Pleiades**, a lovely sight in binoculars.

Above Orion and Taurus is a pentagon of second and third-magnitude stars with a bright luminary at one apex. The constellation is **Auriga** the Charioteer, and the bright star is **Capella**. Capella is similar in color and temperature to our Sun, but much brighter intrinsically. Try exploring in the center of Auriga from a dark-sky location with a pair of binoculars. The **Milky Way** runs through part of Auriga, providing a horde of faint stars and several star clusters at or just below the limit of most people's unaided eyesight.

Following along the Milky Way down toward the northwestern horizon, you'll find two more constellations — **Perseus** and **Cassiopeia**. Neither can be seen well at this season, but the W-shape that marks Cassiopeia's chair (she is a queen seated on a throne in mythology) is quite distinct.

Let's go back to Orion and look to the southeast of him. Immediately your eye will spy a brilliant point of light; this is **Sirius**, the chief star in **Canis Major** the Great Dog. The figure of Canis Major shows a dog rearing on his hindpaws, reaching up toward Orion, his master. See if you can imagine hindquarters out of the stars below and to the left of Sirius and an extended paw in the star directly to the west of Sirius.

About on a level with Betelgeuse and about as far to the northeast of Sirius as Betelgeuse is to the northwest of it, a bright star stands alone in a dim region of sky. This is **Procyon**, the main star of **Canis Minor** the Small Dog. (Zoologists, familiar with the name in another way, might think of Procyon as the "raccoon" star!)

North of Procyon lies the zodiacal constellation **Gemini** the Twins, with their two namesake stars, **Castor** and **Pollux**, representing the twins' heads. Castor is the more northern of the two and is slightly dimmer than Pollux. The twins stand with their feet stretched out toward Orion, their toes just dipping into the Milky Way. Take binoculars and scan slowly along a line between Castor and Aldebaran; about halfway is a small knot of stars near the foot of one of the Twins. This is a pretty little open cluster, called **M-35** (after its position in a list of clusters and nebulae compiled by the 18th century French astronomer Charles Messier). It is also just visible to the naked eye under good conditions.

Shifting our attention to the eastern half of the sky, we will greet the stars of spring as they rise. High in the southeast lies a bright white-colored star, **Regulus**. Regulus is the chief luminary in the constellation **Leo** the Lion. Like Taurus and Gemini, Leo is a zodiacal constellation, and in fact, Regulus lies almost exactly on the path (called the ecliptic) taken by the Sun in its apparent yearly circuit of the skies. It's not hard to see a leonine or sphinx-like profile in Leo's stars. Regulus represents his elbow and the backward question mark that curls northward from Regulus — the "Sickle" — marks his chest and head. His hindquarters and tail are formed by a triangle of stars whose westernmost point is second magnitude **Denebola**.

To the north of Leo lies his companion, **Leo Minor** the Small Lion. Unlike Canis Minor, which boasts of at least one bright star, Leo Minor's are all of fourth and fifth magnitude. It is also the first constellation we've observed so far tonight that does not date back to antiquity. Leo Minor was created by the Danzig astronomer Johannes Hevelius in 1690 to fill an otherwise empty patch of sky. Around that time, when the first modern charts of the sky were drawn up, several astronomers took the opportunity to fill up the spaces between the classical star groups with others of their own making. Most of the new constellations died with their creators, but Leo Minor has survived.

Between Leo and Gemini lies a dark stretch of sky, but it is far from empty. This is the location of the zodiacal constellation, **Cancer** the Crab. Cancer has no bright stars, and from an urban location you may have difficulty spotting anything here at all. Yet the ancients, living with pre-industrial skies, had no trouble creating the figure or in discerning a faint nebulous patch in the center of the Crab. They named the nebula **Praesepe** ("the Manger"); it has also been called the Beehive and M-44. In actuality, it is a loose open cluster of stars that hovers on the threshold of naked-eye visibility. It will resolve into stars when you turn any optical aid — binoculars, even opera glasses — on it.

Below Cancer, about midway between Regulus and Procyon, lies a trickle of third and fourth-magnitude stars that forms the head of **Hydra** the Water Snake. Hydra is the longest constellation in the sky: we see its head here, but its body extends far over to the east where it joins the stars of early summer; it also dips low toward the south. Its one bright star, **Alphard**, is second magnitude.

Extending to the north and west of Cancer lies another dim constellation, **Lynx**. Although loosely similar to Hydra in brightness, Lynx is not as well defined. It, too, is one of Hevelius' creations.

Directly below Regulus is another coinage by Hevelius, **Sextans** the Sextant. Hevelius created it out of a few fourth and fifth-magnitude stars that had not been claimed by their neighbors. It is a grouping to look for and to trace out when you're under dark country skies.

Sextans' neighbor to the east is the first of two adjoining constellations frequently paired, **Crater** the Cup and **Corvus** the Crow. Neither constellation is very prominent; both have second through fourth-magnitude stars. The "cup" of Crater actually looks more like a goblet since there is a stem of three or four stars extending toward the southeast. It's a lot harder to see the crow in Corvus than the cup in Crater, but some depictions show the Cup tipped to pour something — water? wine? — onto the Crow's tail.

A look into the northeast will reveal a familiar asterism, the **Big Dipper**. The Dipper is only the brightest part of a much larger constellation, **Ursa Major** the Great Bear. We'll explore it in more detail in late spring, when it will be higher. For now, follow the curving arc of the Dipper's handle past its end — it seems to point to a reddish star rising in the east-northeast. This is **Arcturus**, the brightest star of **Bootes** the Herdsman.

Between Arcturus and Denebola in Leo lies a dim constellation, **Coma Berenices**, Berenice's Hair. This will be a pretty region of sky to scan with binoculars when it gets higher, but for the moment let's just note it and finish off tonight's observing by glancing at the bright white star low in the east-southeast. This is **Spica**, the first-magnitude beacon-star in **Virgo** the Virgin. We'll see Virgo much better in a month or two.

Early Spring

Chart shows the sky on:
10:00 p.m. on March 1
9:00 p.m. on March 15
8:00 p.m. on April 1
7:00 p.m. on April 15
7:00 p.m. (Daylight Time) on May 1

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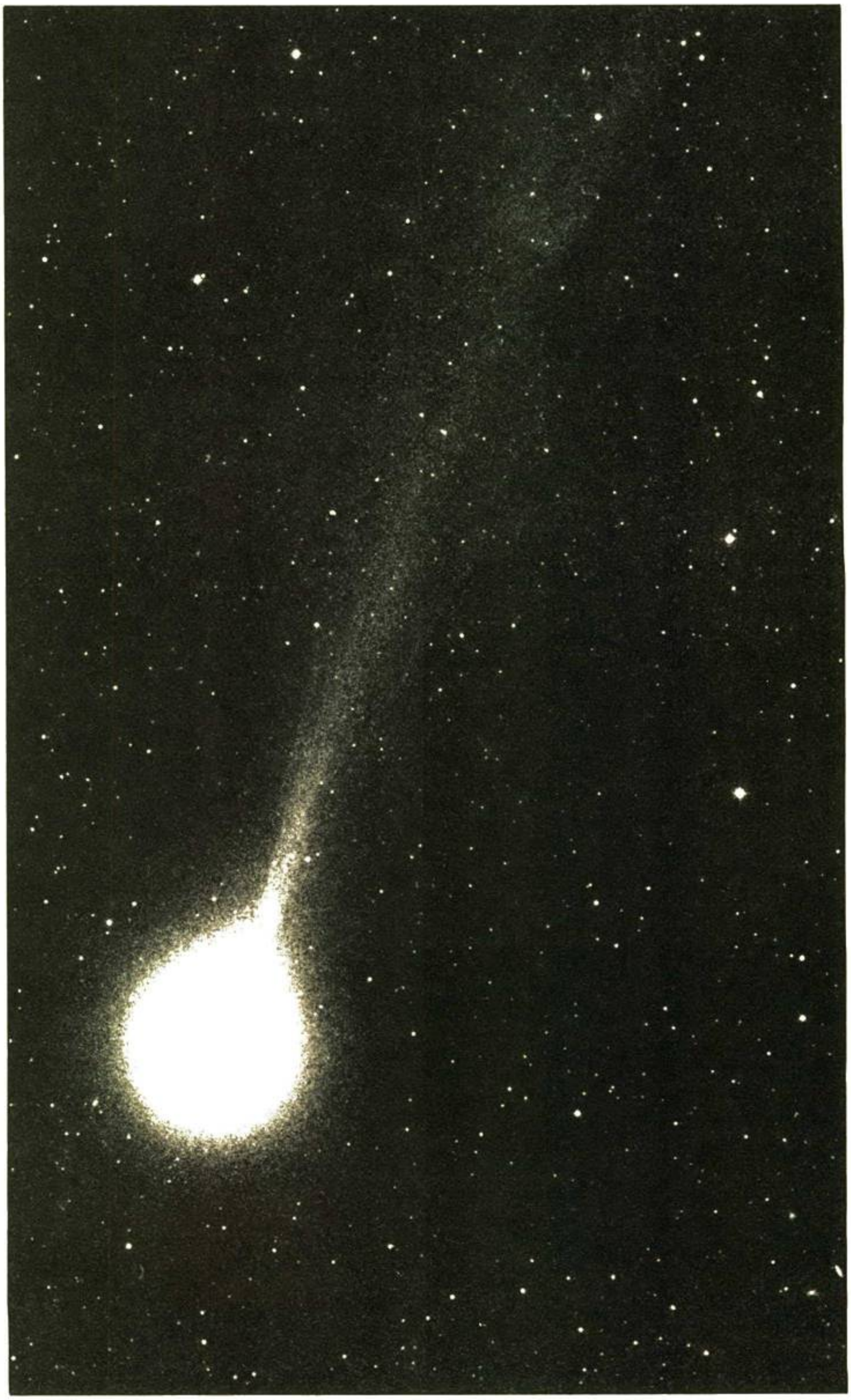
The Changing Face of Comet Halley

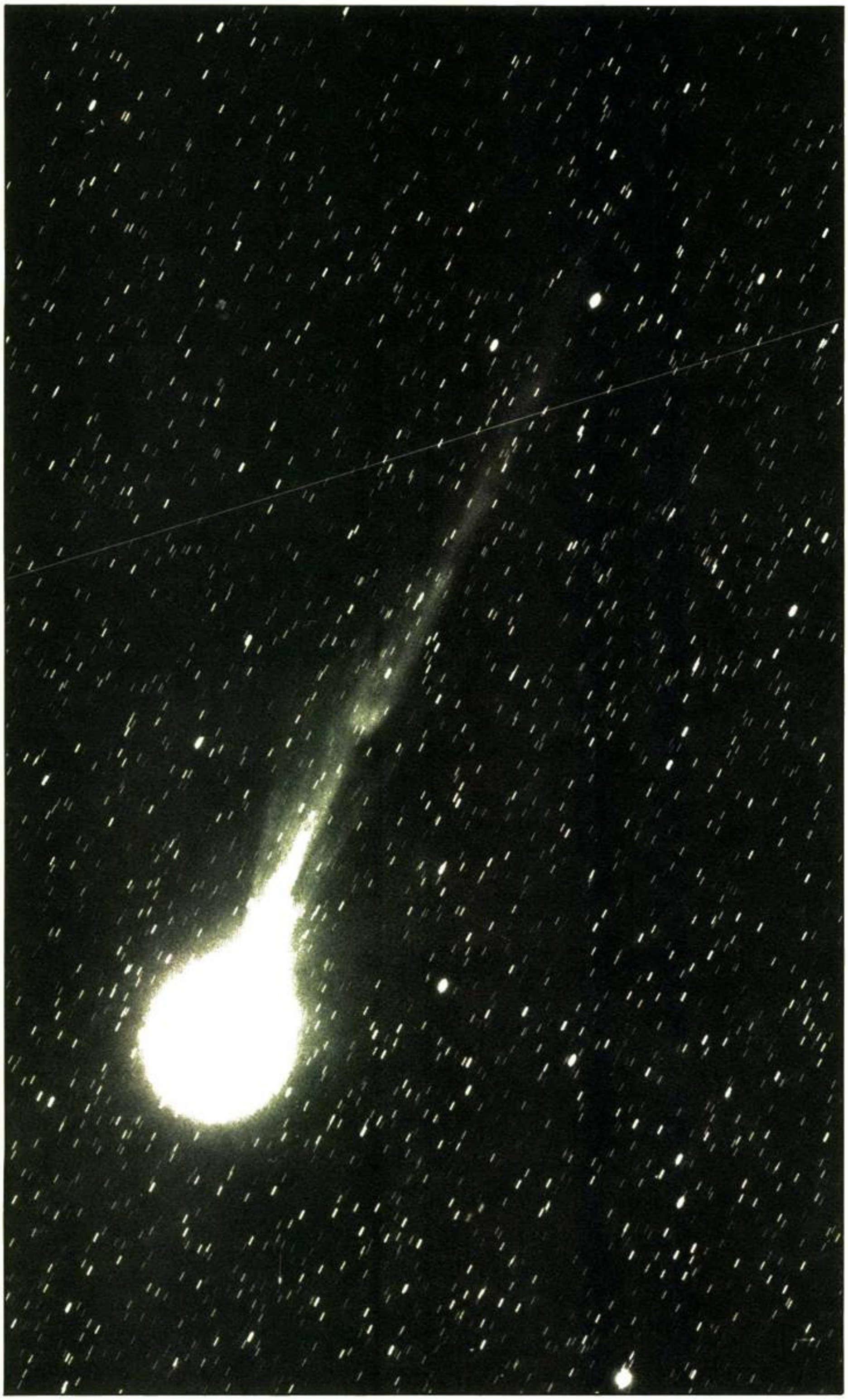
Gas Tail. Halley's Comet appeared dim at first but rapidly brightened and gave astronomers plenty of activity to interpret. In mid-December Halley developed an intricate gas tail, giving astronomers their first chance to observe Halley's complex structure with modern instruments.

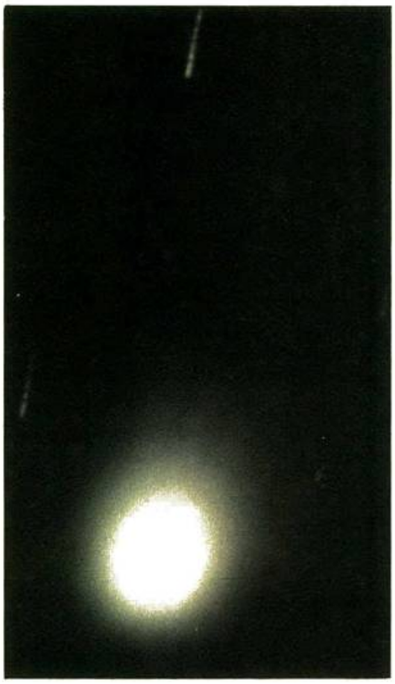
Eleanor Helin of the Jet Propulsion Laboratory photographed the comet (right) on December 13 using the 1.2-meter Schmidt telescope on Palomar Mountain, California. The photograph shows "a billowing stream of electrified gases, carbon monoxide, and water vapor some 18 million kilometers long," and detail such as "tail rays, kinks, condensations, and a helical structure visible as a wavy texture."

One night later Richard E. Hill photographed the comet (opposite page) from the Warner and Swasey Observatory on Kitt Peak, Arizona. (The streak was caused by a passing satellite.) As these photos show, the tail changed its appearance dramatically in a single day.

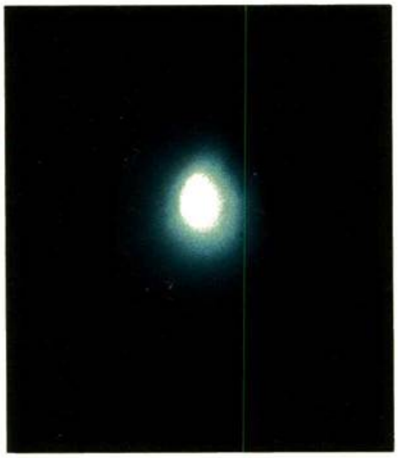


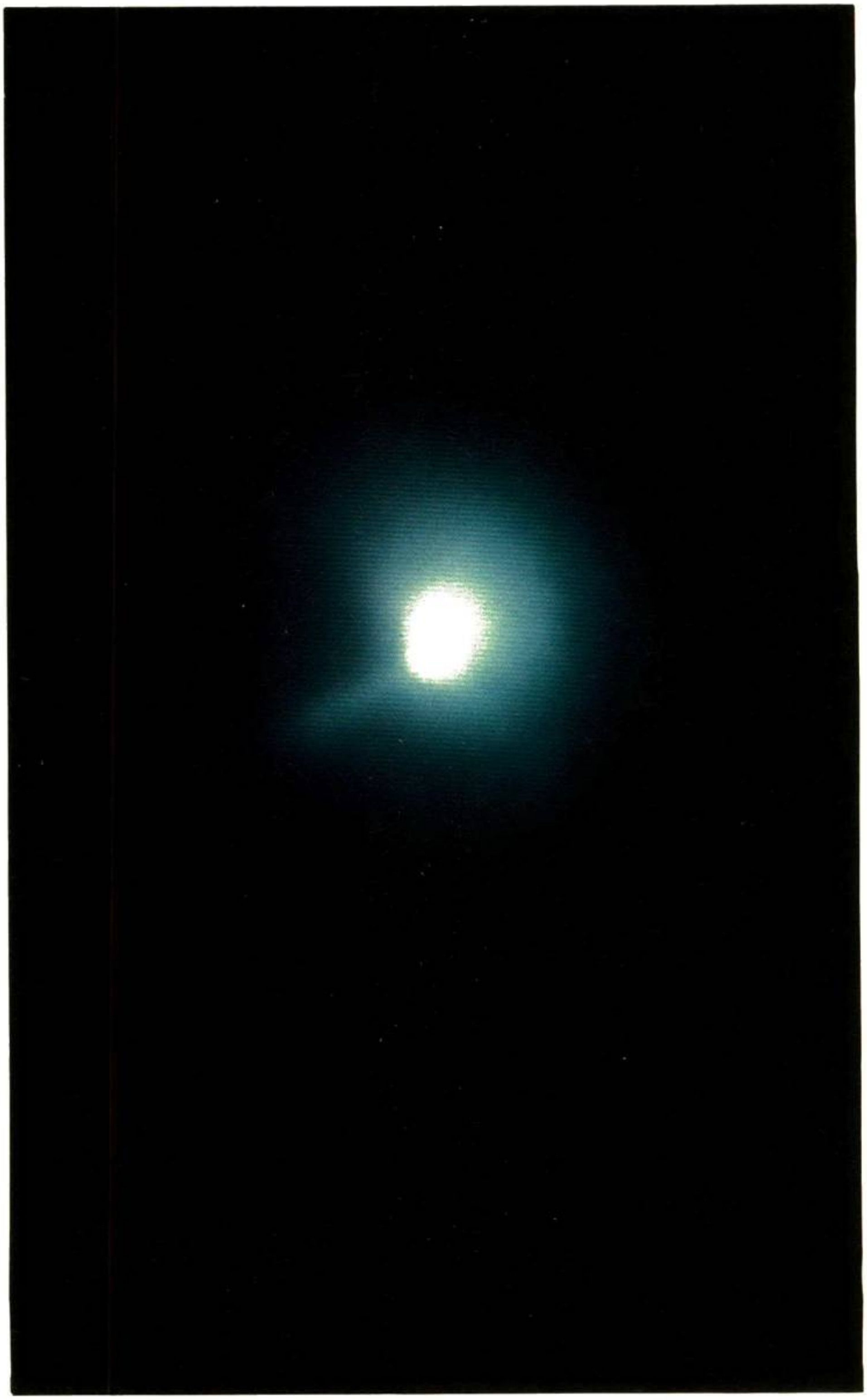
Before Halley disappeared behind the Sun in January, astronomers armed with computer-aided cameras and huge telescopes captured the comet's many intricate features.



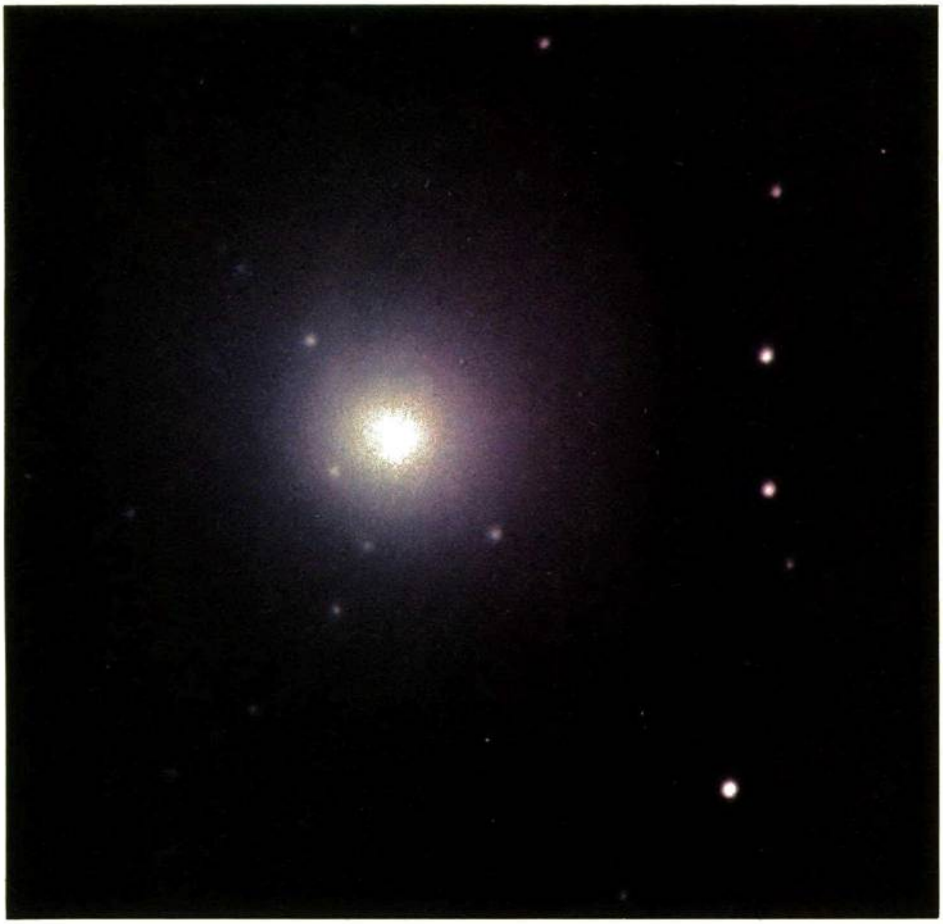


Inner Coma. On January 11 Art Whipple of McDonald Observatory in Fort Davis, Texas, made this exposure showing Halley's inner coma and gas tail. It is a 20-minute exposure made with McDonald's 2.1-meter reflector.

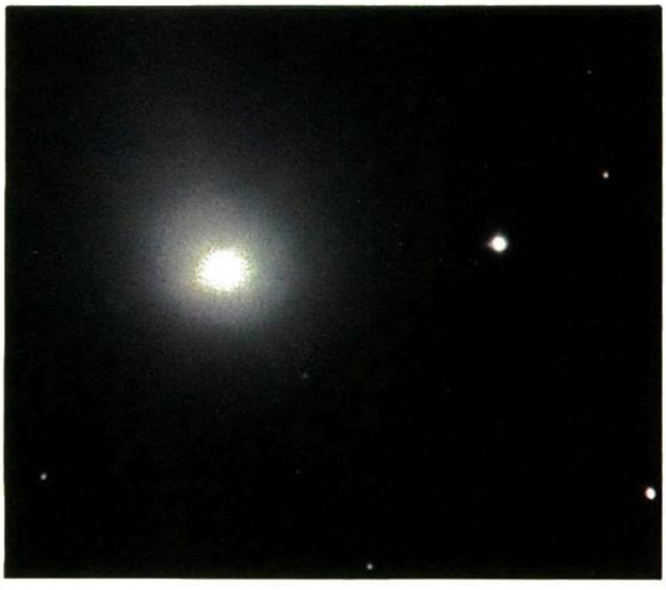


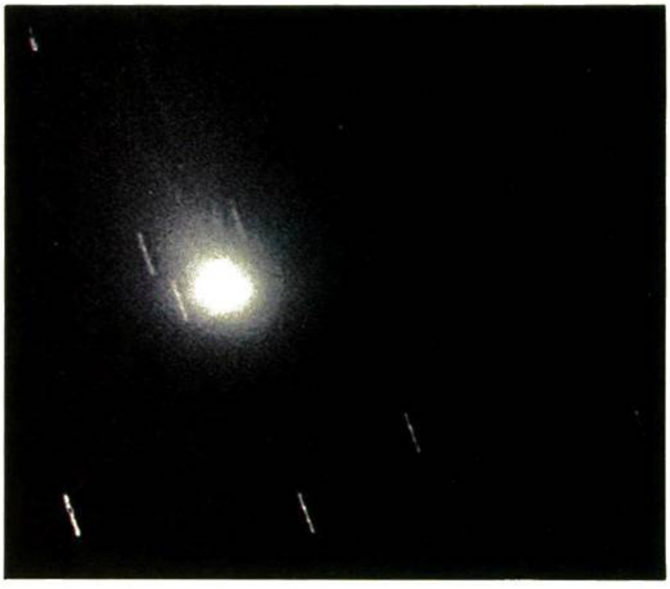


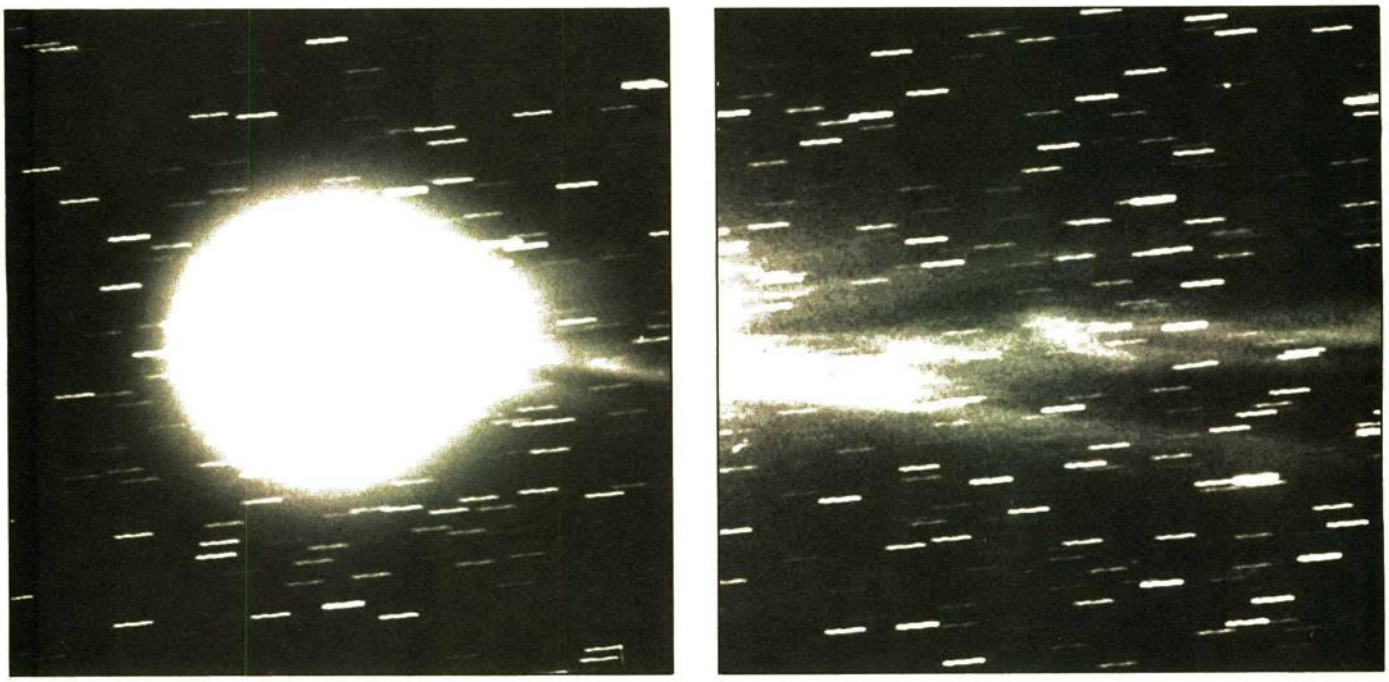
Nuclear Jets. Not all astronomers are studying the comet's gas tail, however. At the University of Arizona's Lunar and Planetary Lab, Stephen M. Larson and David H. Levy have been using a 61-inch telescope equipped with a CCD camera to observe rapidly changing jets emanating from the comet's nucleus. On January 6 Larson and Levy recorded an enormous dust jet (right) spurting from the cracked and warmed surface of the nucleus. Several days earlier (above) the jet was not visible.



Gas and Dust Comae. The University of Arizona's 61-inch telescope has also been used to study Halley at various discrete filtered wavelengths. Astronomers Uwe Fink, Al Schultz, and Mike DiSanti regularly photographed the comet using a CCD camera. Their November 14 photograph (left) shows Halley through a V filter, which primarily transmits C_2 emission wavelengths. A red-filtered photo made on December 7 (bottom left) reveals Halley's extensive dust coma shining by reflected sunlight. The photo at bottom right is a long exposure taken with a special filter that transmits light from ionized water molecules. The method by which the solar wind and these molecules interact is unknown but could be deduced using images like these.







Multiple Gas Tails. On December 11 David Jewett and Karen Meech of MIT succeeded in producing one of the first detailed overall photographs of Halley's extensive tail. They used the Burrell Schmidt telescope on Kitt Peak, Arizona, to make several overlapping frames that together document the comet's 10-million-kilometer-long tail, which is mainly composed of ionized carbon monoxide. The photo dramatically shows two separate strands of gas that, according to Jewett, are "streaming away from the nucleus at 100,000 miles per hour."

Inner Coma. Six days before the Jewett/Meech composite was made, McDonald astronomer Art Whipple created this photo of the extreme inner coma of Comet Halley. Whipple used McDonald's 2.1-meter telescope and a 32-minute exposure on IIIa-J film.

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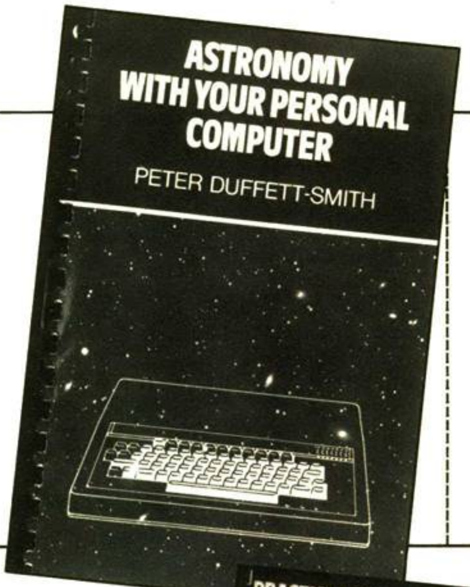
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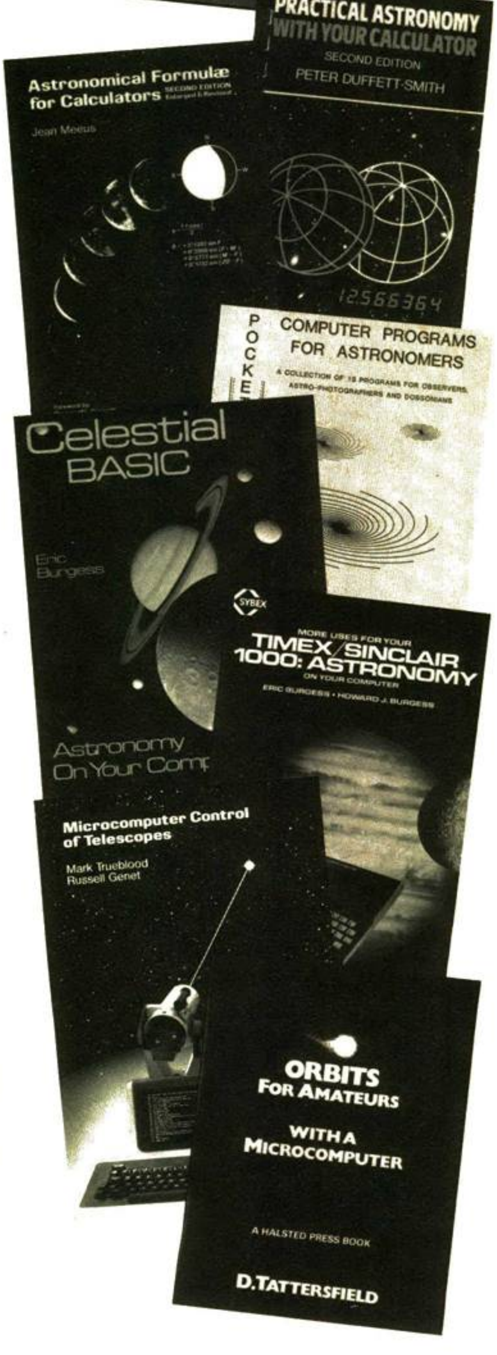
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After Halley... Saturn At Opposition

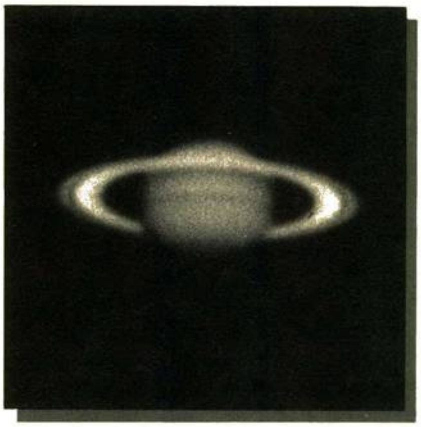
by
Jeff Kanipe

If you have recently purchased a telescope and are wondering what else might be up there to look at besides Comet Halley, why not try observing Saturn? Saturn is a good object to break in a new telescope with because it can be as easy or as challenging as you like. The planet has enough features to occupy anyone casually looking at it in the eyepiece, and there are also additional details that require taking your telescope to the outer limits of light grasp and definition.

This month Saturn is approaching opposition, which is typically one of the best times to observe the ringed wonder and certainly the best opportunity to see features you may have never seen before.

But any time is a good time to observe Saturn. It never fails to draw gasps, oohs, and ahhs from star-party members or the solitary observer hunched over his telescope in the quiet of his backyard. As seen in a 6-inch reflector, the planet contrasts strikingly against the black sky: the rings are razor sharp and the flaxen-hued globe is obviously flattened at the poles like a goldfish bowl. Titan, Saturn's brightest moon, can easily be picked out, and other moons may be visible. From an aesthetic standpoint, Saturn is one beautiful planet.

Saturn is also attractive as a challenge. Many backyard observers have made a lifelong hobby of studying the planet and its subtle, elusive character. Features within the planet's belts and rings are typically difficult to see, even in moderate-sized telescopes, partly because of Saturn's great distance from Earth. Opposition, however, decreases that distance and slightly improves the telescopic view.



Thomas Rotkiewicz

Saturn reaches opposition on May 28 when it will be 180° opposite the Sun as seen from Earth. This places the Earth directly between the Sun and Saturn so that the planet is fully illuminated by the Sun. Because Saturn is opposite the Sun in the sky, it rises as the Sun sets, affording all-night viewing. At midnight, Saturn is directly overhead; by the time Saturn is setting, the Sun is rising. Each day after opposition, Earth will begin to edge ahead of Saturn in its orbit about the Sun. Nevertheless, the great ringed planet will remain well placed in the evening sky for several months to come.

Look for Saturn low in the southeast about 10:00 p.m. local time in the constellation Scorpius. In moderately dark skies, Scorpius is a prominent J-shaped star grouping with bright orange Antares located just south of the Scorpion's head. The hook of the Scorpion's tail will still be very low on the horizon. Saturn will be the bright ivory-white "star" 7° north-northwest of the slightly fainter Antares. If you are still confused as to which of the two objects is Saturn, just remember that it is the one highest above the horizon.

Observing Factors

You can increase your observing edge for this opposition if you have the right telescope, use magnification wisely, and observe when seeing conditions are optimal. A telescope in the 3- to 6-inch range should be able to resolve the rings, Cassini's Division, and Titan. Wavering images will likely be due to atmospheric turbulence, about which there is nothing you can do. Fuzzy, blurry images may be due to a combination of bad seeing and too much magnification.

The kind of telescope used will determine how "resolvable" Saturn appears in the eyepiece. The greater the telescope's aperture, the more light is collected, which translates into better resolution. Just as important, however, is the instrument's focal ratio (focal length divided by aperture); in this case, the larger the better since larger focal ratios yield larger image scales. Newtonian focal ratios of f/6 are satisfactory for planetary observations with f/8 or greater being preferred. (Telescopes with focal ratios below f/6, although effective for deep-sky observing, are generally not suitable for planetary viewing because of their wide fields of view and lesser degree of resolution.) If you can manage to couple an adequate focal ratio with enough aperture, your views will come in bright and with more than enough definition.

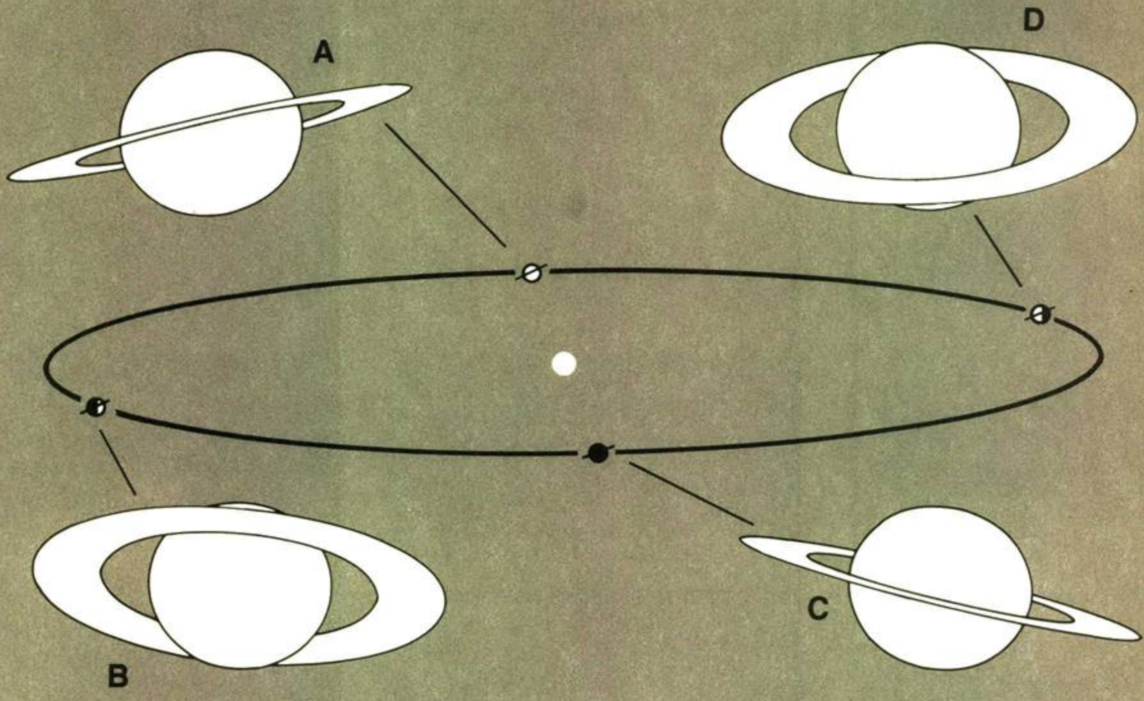
Experiment with magnification. Generally, 30x per inch of aperture is about right for average seeing. If you are using an 8-inch scope, you can usually go as far as about 240x before the image begins to degrade. However, if the image is steady at this magnification try boosting it a bit more until the image becomes "watery." At this point, back off on the magnification until the image becomes manageable again. Don't force higher magnification if the seeing won't accommodate it.

A small telescope can actually have an advantage over a larger instrument when observing Saturn. Though large apertures resolve more detail, they also resolve more atmospheric turbulence and pick up more stray light as well. Observing planets requires high resolution and high magnification so if the seeing is not good, a smaller telescope may be a distinct advantage since it is taking in a smaller area of sky.

Saturn observations can be divided into three components: the globe, the ring system, and the satellites. All three areas have their own little quirks that can both delight and frustrate observers. Basically, the rings can be glimpsed with a 2.5-inch telescope; even binoculars will show a

Saturn's Changing Rings

The changing angle of Saturn's rings results from the planet's rotation about a tilted axis and its position with respect to Earth. The rings appear edge-on at A and C and reach their maximum inclination at B and D.



distinctly oval appearance. Observers with 6- to 8-inch telescopes should be able to see bright surface features on the globe, the distinct A and B bands within the ring system, Cassini's Division, and at least three or four satellites.

Features On the Globe

Saturn has a mean apparent diameter of about 18 arcseconds, which is too small for the human eye to discern as a disk. At opposition, this increases to 20 arcseconds, which is about half the mean diameter of Jupiter or roughly the size of a quarter seen 860 feet away. This seemingly insignificant gain in angular diameter, coupled with a fully illuminated planet, means that this is the best time for observers with small telescopes to see the notoriously subtle surface features within the belts and zones of Saturn.

During this opposition, Saturn's northern hemisphere will be tipped toward us, but because a telescope inverts its subjects, the view will appear as if we are looking "up" from beneath the planet. Thus Saturn's near ring will be tilted up and cover the globe's south pole and much of the southern temperate region; the far ring will be tilted down behind the northern hemisphere at the pole.

The globe's overall color varies from light brown to a pale, chalky yellow with the poles usually somewhat duskier in hue and the equatorial region normally the brightest area on the planet. Saturn is also scored with a number of detectable belts, but they are often featureless and so diffuse along their borders that it is difficult to say where one ends and the other begins.

With a 6- or 8-inch telescope about the best you can do is differentiate the lighter areas from the darker areas on the globe. You will not see the degree of detail that you can on Jupiter. The best way to try to see surface features is to use high powers, observe on nights of good seeing, and concentrate on Saturn's "hot spots" — active surface areas found in the north and south temperate zones (around 40° latitude on either side of the equator) and the equatorial region, which is also known to vary in brightness. Sometimes a particular zone will darken or split and become double, as do the north and south equatorial belts on occasion. But for the most part, noticeable features within Saturn's clouds are just too difficult to see.

Saturn presents a more quiescent face than Jupiter's roiling atmosphere because it is located farther from the Sun and is colder. Consequently, most of Saturn's convective activity occurs deep within its cloud layers where the atmosphere is denser and hotter. The planet's upper atmosphere is covered by a smoggy haze of ammonia cirrus clouds that effectively hide the turbulent activity going on below. Even images from the Voyager space probes had to be computer enhanced to bring out features below this haze.

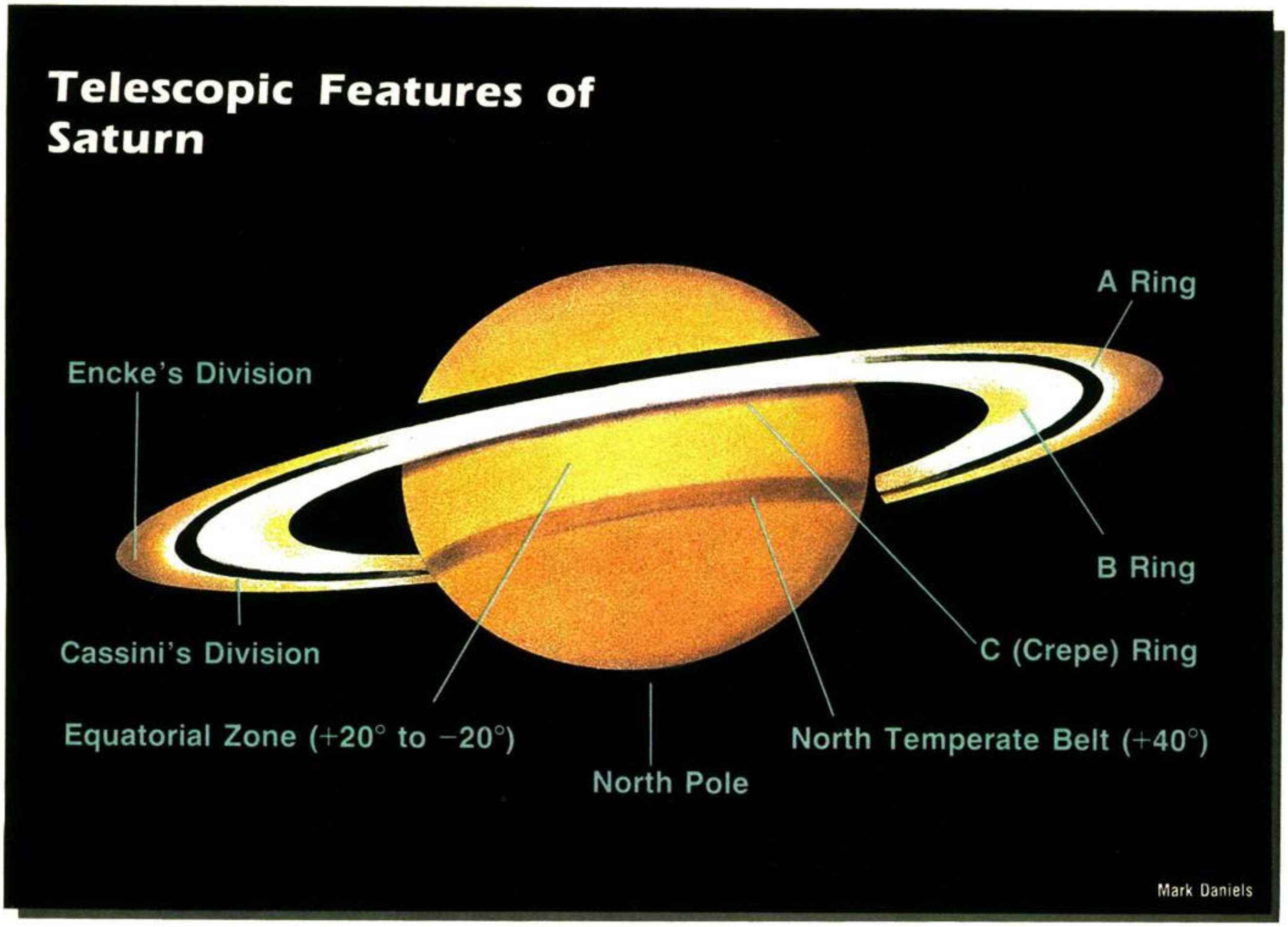
Occasionally an outbreak of spot activity occurs within Saturn's belts — especially in the temperate regions — but such an event is rare and usually beyond the resolution of 6- to 8-inch scopes. The description of these spots varies widely, ranging from dusky ovals to singular white spots, apparently the rarest of Saturnian blemishes. Still, it is possible to see these spots in small telescopes. Again, watch for them in the equatorial belt and the north temperate zone, which will be more prominently exposed than their southern counterparts during this opposition.

The Rings

The rings, inclined 25.3° to our line of sight, are favorably placed for the May 28 opposition. (They will be tilted at their greatest extent, about 26.5°, during Saturn's June 1988 opposition.) Most of Saturn's brightness is, in fact, reflected light from the rings. Saturn's brightness at opposition fluctuates from magnitude 0.6 to 0.0 — almost a factor of two — mainly due to the increased inclination of the rings.

With small telescopes, three main rings and one or two divisions are visible. The outermost A ring is about 10,000 miles wide and is fairly transparent, owing to its low particle density. Some observers

Telescopic Features of Saturn



Mark Daniels

describe this ring as having a yellowish color similar to the temperate regions of the planet. The A ring should be easy to see in a 3-inch scope.

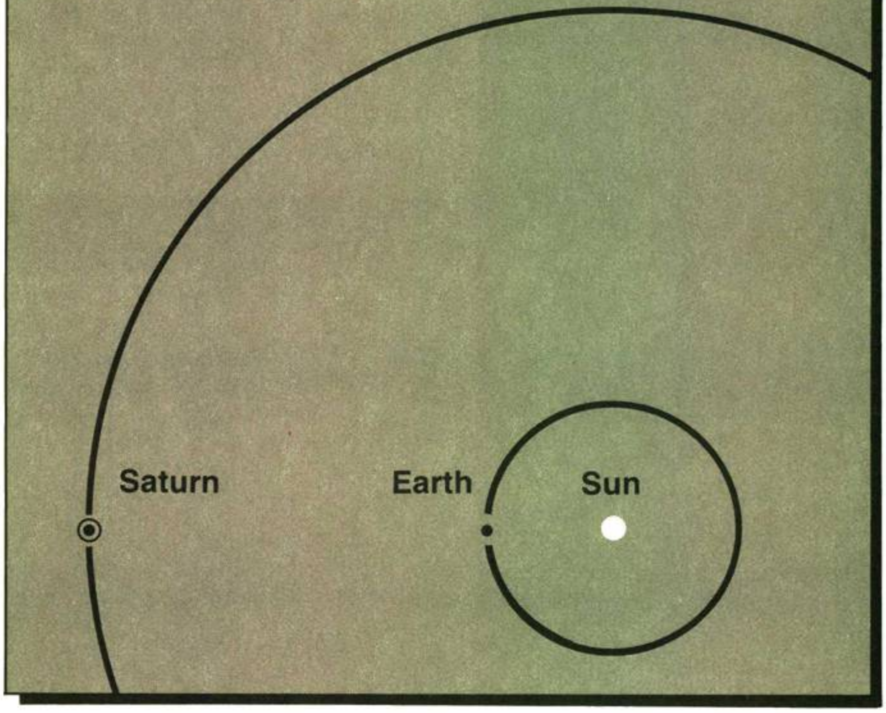
The B ring is the brightest and broadest ring segment. This ring is usually the brightest feature of the entire planet, which makes it a rather dependable comparison for fluctuations in the brightness of the equatorial belt. The B ring is creamy white in color and measures well over 16,000 miles wide. This is undoubtedly the densest ring in the system, though stars have been observed shining dimly through it during occultations.

Separating the A and B rings is the pencil-thin Cassini's Division, named for the Italian-French astronomer Giovanni Cassini. With the rings inclined as much as they are during this opposition, the division should not be difficult to see in a 3-inch scope. It will become more of a challenge, however, as the tilt of the rings decreases and they slowly disappear by the mid-1990s. The division is usually more apparent in the ansae, the outer two ends of the rings as seen from Earth. Far from being a void in the rings, as was long thought, Voyager spacecraft revealed many distinct ringlets within Cassini's Division, that are much less dense than the surrounding rings.

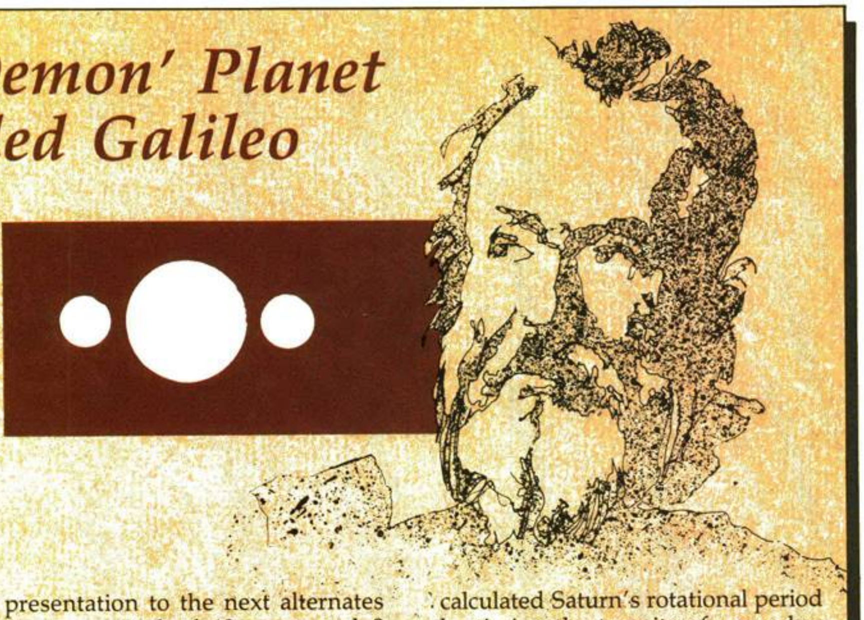
Between the B ring and the planet lies the nearly transparent C ring, or Crepe

Opposition

Opposition occurs when a superior planet (one located outside of Earth's orbit) is positioned exactly opposite the Sun as seen from Earth. During this time, the planet rises at sunset, is overhead at midnight, and sets at sunrise.



Saturn: The 'Demon' Planet That Confounded Galileo



If you think the view of Saturn in your telescope is not very good, you should have seen what Galileo saw in 1610 when he turned his 1¾-inch "optik" tube upon the distant planet. Galileo saw the rings, but because of his telescope's poor optics he didn't recognize them for what they were. He wrote to the Duke of Tuscany:

"When I view Saturn it seems tricorps. The central body seems the largest. The two others, situated, the one on the east, and the other on the west, seem to touch it. They are like two supporters, who help old Saturn on his way, and always remain at his side."

Galileo did not observe the planet again until 1612. By then the rings had become edge-on and all Galileo saw was the round globe of Saturn. "It is possible that some demon mocked me," he wrote tersely.

By the time Galileo observed the planet again in 1616, he was surprised to see that the bodies on both sides of the globe looked very different. "The two companions are no longer two small perfectly round globes," he wrote, "but are at present much larger and no longer round . . . that is, two half eclipses with two little dark triangles in the middle of the figures and contiguous to the middle globe of Saturn, which is seen, as always, perfectly round."

It wasn't until March 1655 that Christian Huygens, using a 2.3-inch refractor with a 23-foot focal length, solved the mystery: Saturn was surrounded by a thin ring that did not touch the planet. The discovery was so incredible that Huygens recorded it in an anagram to ensure the priority of his find as well as to protect his reputation until he could double check his facts with further observations.

In a year the ring had disappeared and Huygens saw Saturn as Galileo had forty-five years earlier. Patiently, Huygens waited until, in October 1656, he saw the ring re-appear. "It is girdled by a thin plain ring," he wrote, "nowhere touching, inclined to the ecliptic."

Huygens calculated that, because of Saturn's inclination to the plane of the solar system, the ring would appear edgewise as seen from Earth every fourteen years. (Actually, the interval from one edge-on presentation to the next alternates from a period of 13 years and 9 months to 15 years and 9 months, with the north pole of the planet tilted toward Earth during the longer interval and the south pole facing Earth during the shorter interval. This variation is due to the ellipticity of Saturn's orbit.) In addition, Huygens discovered the planet's largest moon, Titan, and observed some banded features on Saturn that were similar to Jupiter's, although fainter.

Fifteen years later, the Italian-French astronomer Giovanni Cassini, using a 100-foot-long telescope, discovered a moon just off the western extension of Saturn's ring. This was Iapetus. Cassini was fortunate to see this satellite as it presented its most reflective hemisphere toward Earth. When the moon's eastern elongation occurred, its least reflective side was presented and Cassini could not find it. The discovery of Rhea later that year and Dione and Tethys in 1684 all occurred when the ring was practically edge-on and its glare was at a minimum.

But it was in 1675 that Cassini made a discovery that would forever make his name a part of the Saturnian landscape. He observed a thin, dark gap dividing the ring that has come to be known as Cassini's Division. This discovery meant that there were two separate rings surrounding Saturn, not just one solid spinning disk, which was the reigning theory at that time.

A century later, William Herschel discovered two more moons, Enceladus and Mimas, during his first night of observing the planet using a 40-foot-long, 48-inch reflector. This brought the total to seven moons.

In 1793 and early 1794, Herschel calculated Saturn's rotational period by timing the transits of a number of "irregularities" he had seen on the globe. He made these difficult observations at the very limit of his telescope's ability. Nevertheless, Herschel derived a rotational rate of 10 hours and 16 minutes. Modern measurements place Saturn's true rotational period at 10 hours and 39.4 minutes. Not bad for eighteenth-century telescopes!

Discovery of the notoriously transparent Crepe Ring was made by degrees. In the early 1800s, various observers — most of them using small to moderate-sized apertures — were reporting that the inside of the B ring was indistinct. Others even reported seeing a dusky band. But it wasn't until the mid-1800s that the Crepe Ring was well confirmed and became accepted as an established part of Saturn's ring system.

Obviously, as telescopes improved, so did the quality of observations. But it was a long, slow process. The very early telescopes commonly had small apertures and long focal lengths. Moreover, the materials used in building telescopes — particularly the glass — were inferior. The kind of clear, flawless glass required for true achromatic refractors wasn't produced until the late 1700s.

Considering all of these factors, it is a wonder Galileo saw anything at all through his 1¾-inch telescope. But he did, as did many subsequent astronomers who used only slightly improved versions. Galileo would no doubt be astounded at many of today's quality off-the-shelf astronomical telescopes, any one of which can plainly show the rings of Saturn, the moons of Jupiter, and more than a few other wonders of the universe.

In a telescope, our view of Saturn during this spring's opposition is from "below" the planet, with its north pole tipped toward Earth. Cassini's Division is plainly visible at each end of the rings as is the subtler north temperate belt, which crosses the planet between the north pole and the equator. Photo by Mike Simmons.

Ring. This ring is difficult to see in telescopes smaller than 8-inches in aperture; in larger scopes it's still pretty tough, but that doesn't mean you shouldn't try to see it with smaller telescopes. Your best bet for seeing this elusive feature is to look for the silhouette of the ring in front of the globe. The Crepe Ring is about 10,000 miles wide and, as the name implies, it is not very dense. However, this ring does undergo some interesting changes in brightness so it warrants monitoring by observers.

An interesting feature that is best seen about sixty days before and after opposition is the shadow that the globe casts on the rings behind Saturn. Before opposition, the shadow will be on the western side of the planet; after opposition, it will be on the eastern side. This feature appears as a black, angular void across the face of the rings just to one side of the globe. At opposition, no shadow is visible.

If you can get your hands on a 10- or 12-inch telescope, try looking for the elusive Encke Division located at the outer edge of the A ring. This is commonly a difficult feature to make out and it's not unusual for one observer to see it while another doesn't, even though both are looking through the same telescope! Look for an area of subtle, dark shading rimming the outer A ring that is not as sharply defined as Cassini's Division.

The Satellites

Of the nine major satellites, four can be seen with a 6-inch scope and a fifth can be made out under excellent seeing conditions. However, glare from the rings during this opposition will limit the number of satellites that are visible. (Veteran observers prefer to concentrate on the satellites when the rings are edge-on and ring glare is at a minimum.)

Like Jupiter's moons, the satellites of Saturn — except for Iapetus and Phoebe — orbit close to the equatorial plane, as do the rings. But currently this plane is inclined slightly over 25°, so Saturn's moons do not appear in a straight line as do Jupiter's.

Saturn's brightest moon, Titan, is easily visible in a 3-inch scope. It is not a closely orbiting moon and many first-time observers mistake it for a background star. Titan is the only moon in the solar system known to have an extensive permanent atmosphere. It is also the second-largest satellite in the solar system, having a diameter of about 5,150 kilometers, not including its cloud envelope. On May 28, look for 8.4-magnitude Titan a little over four ring diameters east of Saturn. Titan will be at greatest eastern elongation — the outermost point of its orbit on the eastern side of the planet — on that day and should be easily visible in a 1.5-inch aperture telescope.

The other telescopic moons (in order of decreasing visibility) are Rhea, Tethys, Dione, Enceladus, and Iapetus when at greatest western elongation. Mimas, Hyperion, and Phoebe are much fainter and require a 12-inch or larger scope to see. With moderate powers, Rhea, Tethys, Dione, and Enceladus are visible hovering about the globe just beyond the rings like gnats around a distant street lamp. Enceladus is closest to Saturn, followed by Tethys and Dione, which is about one ring diameter from the globe at greatest eastern or western elongation. Rhea is about one-and-a-half ring diameters out and, since it is the brightest of these four moons, should also be the most visible.

First-time observers may have a difficult time finding all of Saturn's moons. With time, however, the eye becomes accustomed to seeing fainter objects. The best advice is to keep at it and don't become discouraged if the fainter satellites are not readily apparent.

Studying Saturn

Once you become familiar with Saturn's main features, you may want to pursue more serious study of the planet. In the past, backyard astronomers have contributed quite heavily to our understanding of Saturn's rotational rate and ring density. The majority of white spots on Saturn have, in fact, been reported and confirmed by backyard astronomers.

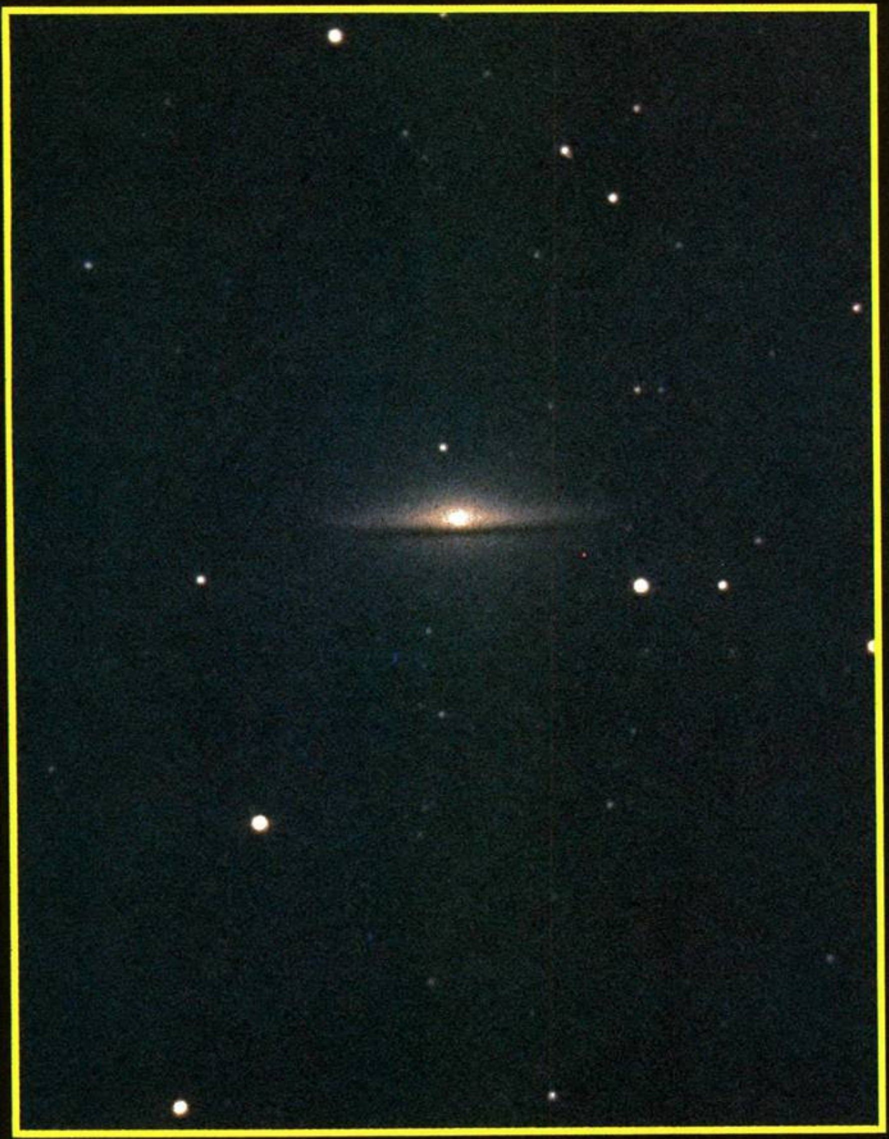
Despite the Voyager flybys, information is still needed in the following areas:

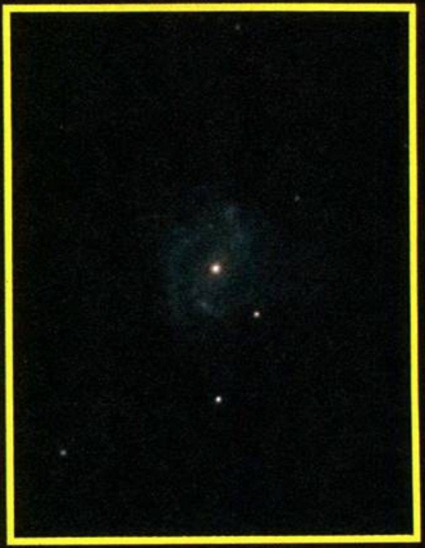
- The discovery and timing of white spots from one central meridian contact to the next. Such data contribute to refinements of Saturn's rotational rate and also indicate areas of convective activity, which could help explain more about the planet's thermal nature.
- The reporting of apparent ring gaps (usually attributed to the gravitational influence of a nearby moon), their apparent brightness or darkness relative to the ring, and their approximate size and position on the ring. Ring gaps are another rare feature (especially for observers with small telescopes), but it doesn't hurt to study the rings for any apparent changes.
- Noticeable changes in the brightness of the rings, especially the Crepe Ring, which is known to vary in visibility.
- How the brightness of stars change as they pass behind the rings. Such data tell us more about the densities of the different rings.

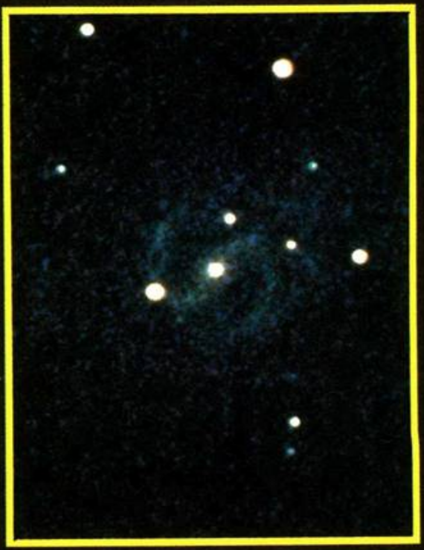
Some of these studies can be quite involved and usually require an equatorial mount with a clock drive. The more advanced projects may require a photometer to measure brightness changes.

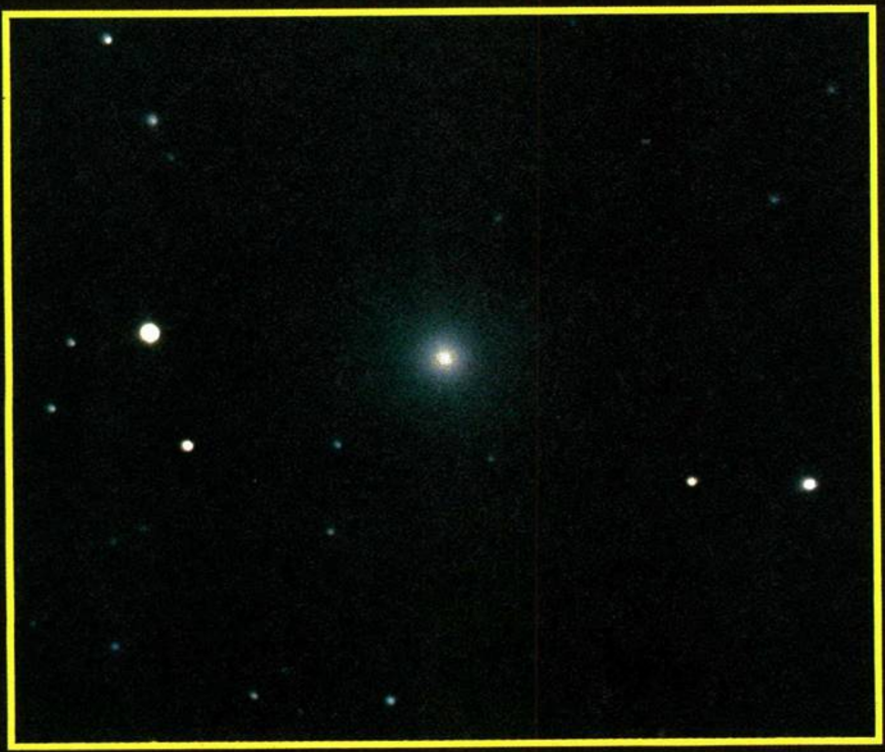
Whether or not you have any of this equipment, if you believe you have observed something significant — a white or brown spot on the globe or some change in the brightness of the rings — send your findings to the recorder of Saturn observations for the Association of Lunar and Planetary Observers, Julius L. Benton, Jr., 1100-A Vincent Rd., Warrington, PA 18976. Include sketches and a detailed description of the phenomenon, give the universal time of your observations, and identify the type of instrument used. If possible, have someone else verify what you have seen.

Above all else, have fun when you observe Saturn. Don't sabotage yourself with expectations that exceed your telescope or powers of perception. Chances are Saturn will be a glorious sight, even if your telescope is a modest one. More than a few dedicated amateurs can trace their love of astronomy back to their first glimpses of the planet in a 2- or 3-inch telescope. Of all the astronomical objects that are visible in small telescopes, Saturn is the one most guaranteed to please.





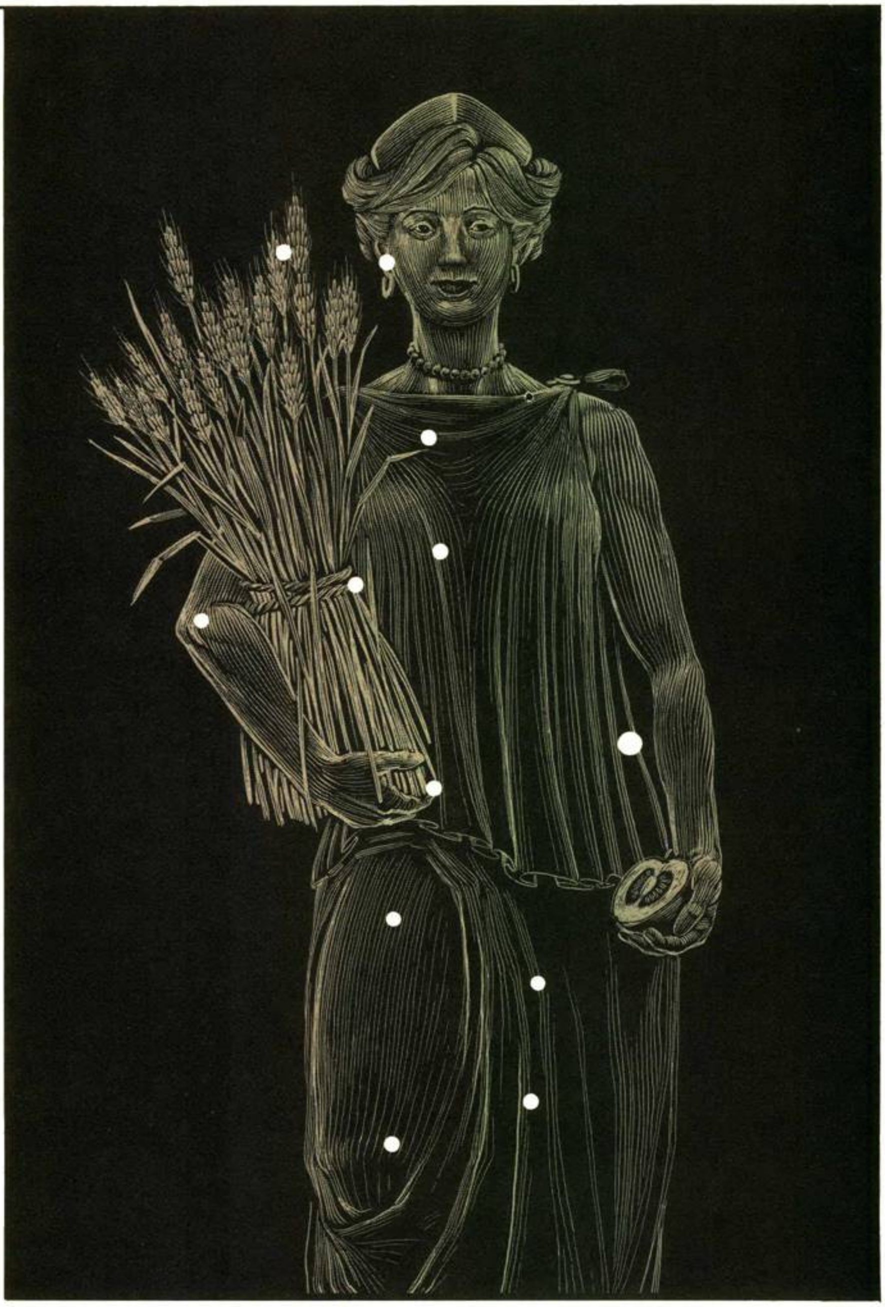




Top left: The Sombrero Galaxy, M-104, is a bright edge-on spiral presenting a broad dark lane to telescopes of 3-inches' or more aperture. Bottom left: Virgo's grand giant elliptical galaxy is M-87, a circular fuzzball in small scopes. Top: You'll need at least an 8-inch scope to detect M-61's subtle face-on spiral structure. Above: NGC-4535 is a face-on barred spiral shining at 10th magnitude. Photos by Jack Newton.

Virgo

Vir
Virginis



Keith Ward

Virgo the Virgin is a galaxy-hunter's paradise; this constellation contains many bright galaxies visible in backyard telescopes. Virgo contains spirals, barred spirals, lenticulars, ellipticals, peculiars — you name it, it's there.

Why is Virgo filled with so many galaxies? This area of sky contains the so-called Virgo cluster of galaxies, the densest concentration of matter in our corner of the universe. This cluster, of which the Milky Way is a remote member, is in turn part of a gigantic group of galaxies called the Local Supercluster, a vast collection of relatively nearby groups of galaxies. Suffice it to say that Virgo's many galaxies will undoubtedly be some of the best visible in your backyard telescope.

Although many of the galaxies in Virgo are large and bright, the center of the Virgo cluster is actually quite distant as groups of bright galaxies go. Redshift measurements vary from galaxy to galaxy in the Virgo cluster, but it seems that the group's center lies at a distance of about 15 megaparsecs.

The best place to start observing is right in the heart of the Virgo cluster, practically on Virgo's northern border with Coma Berenices. Here lie **M-84** (NGC-4374) and **M-86** (NGC-4406), two bright elliptical galaxies that are visible together in a low-power field of view. Separated by 17′, these galaxies appear very similar in most telescopes although M-86 is slightly bigger and brighter than M-84, shining at magnitude 9.2 and measuring 7.4′ x 5.5′ in angular extent. Small scopes show both galaxies as ovals of grayish light with bright centers surrounded by fainter wispy halos of low surface brightness nebulosity. If you observe with a medium- or large-size telescope you'll see several more streaks of light in this same field. These are the elliptical galaxy NGC-4435 and the spiral galaxies NGC-4388, NGC-4402, and NGC-4438.

For information on naked-eye sky viewing, including planets, constellations, and mythology, see **Eye on the Sky**.

About 1.5° southeast of the M-84/M-86 pair is the giant elliptical galaxy **M-87** (NGC-4486), an object of great interest to astrophysicists. As one of the largest and most luminous galaxies known, M-87 is also a strong source of radio and x-ray emission. This intense outpouring of energy corresponds to a luminous jet of material spiraling out from the galaxy's center. This jet was discovered photographically by Heber D. Curtis at Lick Observatory in 1918. Astronomers believe that the intensely energetic material shooting out from M-87's nucleus, and from the nuclei of many other "active" galaxies, results from matter being thrust into a supermassive black hole in the galaxy's core.

Observationally, M-87 looks like a brighter version of M-86; it shines at magnitude 8.6 and measures 7.2′ x 6.8′ across. The jet is far too faint to observe with backyard telescopes, but it can be photographed with large amateur scopes employing large image scales and long exposure times. Within the same low-power field as M-87 are two fainter elliptical galaxies, NGC-4476 and NGC-4378.

Some 1.5° to the northwest of the M-84/M-86 pair is the bright, highly-inclined spiral **NGC-4216**, which lies virtually on top of the Coma Berenices border. At magnitude 10, NGC-4216 is bright enough to spot as a streak of fuzzy light in large finder telescopes on dark nights; it is also easily observable in 2-inch and 3-inch refractors as a smudge of grainy nebulosity. Larger telescopes reveal a bright oval center surrounded by an 8.3′ x 2.2′ haze of very faint light. Inside the bright oval nuclear bulge is a condensed spot of light marking the nucleus. A bright star lies less than 1′ due east of the galaxy's nucleus.

Several interesting galaxies lie east of M-87. **M-90** (NGC-4569) is a bright spiral visible as a featureless, oval patch in small scopes. This galaxy measures 9.5′ x 4.7′ across and shines brightly at magnitude 9.5. A 6-inch telescope at high power shows M-90 as an intensely bright oval of milky nebulosity encased in a huge halo of fainter light. M-90's nuclear bulge is far brighter than its spiral arms. On steady nights, large backyard telescopes show a hint of detail in this galaxy revealing that its arms are mottled with dark nebulosity.

Forty-five arcminutes southwest of M-90 is the diminutive elliptical galaxy **M-89** (NGC-4552). This magnitude 9.8 galaxy is a round object measuring 4.2′ across; it is featureless and rather unexciting in most backyard telescopes. But nearly 1° southeast of M-89 is a much finer galaxy for backyard observers — **M-58** (NGC-4579). This object is a large and bright Sb-type spiral visible as a near-circular haze in small scopes. A 10-inch or 12-inch scope shows M-58 as a 10th-magnitude blob some 5.4′ x 4.4′ in extent with a bright nucleus wrapped in a featureless haze. Although M-58 isn't terrifically detailed, it's large and bright enough to be impressive through most backyard scopes.

Some 30′ southwest of **M-58** is a curious pair of interacting galaxies known as **NGC-4567** and **NGC-4568**, popularly called the Siamese Twins. Each galaxy shines at about magnitude 11 and measures some 3′ x 2′ across, making the pair easy to spot with 4-inch or larger telescopes. Although the two may appear as a single, very oddly shaped galaxy, this is in fact one of the sky's few bright pairs of physically connected galaxies.

About 2° east of the Siamese Twins are two close neighbors, **M-59** (NGC-4621) and **M-60** (NGC-4649). Both are large and bright ellipticals that appear rather similar in the eyepiece. M-60 is brighter by a magnitude and covers a bit more sky. It also has a small elliptical companion — NGC-4647 — just 4′ northwest in the same field of view. M-59 shines at 10th magnitude and measures 5.1′ x 3.4′ across. It appears as a nebulous ball with a bright, condensed nucleus.

Due south of the Virgo cluster's center is a group of three bright galaxies. **M-49** (NGC-4472), a fine example of an elliptical galaxy, is brighter and slightly larger than the giant elliptical M-87. **NGC-4526** is a 10th-magnitude, lens-shaped elliptical seen nearly edge-on; its dimensions are 7.2′ x 2.3′, causing it to appear as a misty brush stroke of nebulosity. **NGC-4535** is a beautiful example of a face-on barred spiral. Its 10th-magnitude light, however, is spread out into a low surface brightness that makes detail rather elusive.

Further south are three unusual galaxies. **M-61** (NGC-4303) is a 10th-magnitude face-on spiral measuring 6.0′ x 5.5′ across. As viewed in large backyard scopes, M-61 is one of the finest small spiral galaxies in the sky. A dark night will permit you to view traces of its delicate spiral arms and pinpoint nucleus. **NGC-4536**, a 10th-magnitude Sc-type spiral, appears as a bright, oval nuclear bulge surrounded by unevenly illuminated nebulosity. About 1.5° west of NGC-4536 is **3C 273**, the sky's brightest quasi-stellar object, or quasar. 3C 273 appears as a 13th-magnitude dot of light when at maximum (its light output is variable) and is difficult to find. But once you spot the correct bluish dot of light, you're seeing an object that lies over one billion parsecs away!

M-104

17.5-inch f/4.5
reflector
270x

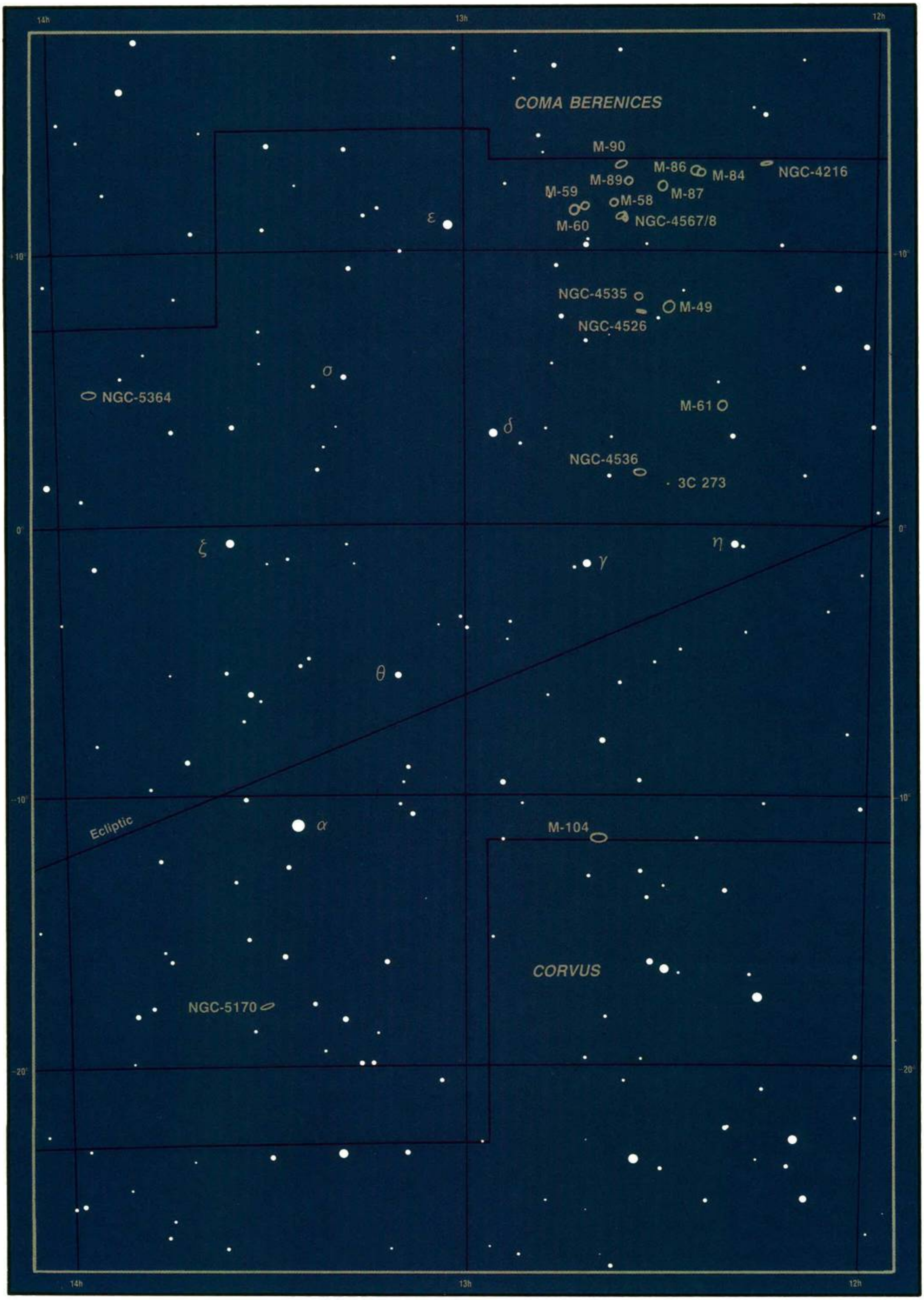
Sketch by David J. Eicher

Far south of this chain of galaxies, extending down from the cluster's center on Virgo's southern border with Corvus, is the finest galaxy in the constellation — **M-104** (NGC-4594). Known as the Sombrero Galaxy because of a prominent dark lane cutting across it, M-104 appears edge-on to our line of sight. The galaxy glows brightly at 8th magnitude and measures 8.9′ x 4.5′ across. M-104 is easy to observe with most any telescope and appears as a flattened saucer bisected by the dust lane. Large scopes reveal a bright disk in the galaxy's center separated by a huge semicircle of nebulosity extending outward on each side. The Sombrero Galaxy, on a good night, is quite a sight.

Object	M#	Type	R.A. (2000)	Dec.	Mag.	Size/Sep./Per.	H
NGC-4216		§	12h 15.9m	+13°09′	10.0	8.3′x2.2′	Sb
NGC-4303	M-61	§	12h 21.9m	+ 4°28′	9.7	6.0′x5.5′	Sc
NGC-4374	M-84	0	12h 25.1m	+12°53′	9.3	5.0′x4.4′	E1
NGC-4406	M-86	0	12h 26.2m	+12°57′	9.2	7.4′x5.5′	E3
3C 273		QSO	12h 29.1m	+ 2°03′	12.9v	stellar	
NGC-4472	M-49	0	12h 29.8m	+ 8°00′	8.4	8.9′x7.4′	E4
NGC-4486	M-87	0	12h 30.8m	+12°24′	8.6	7.2′x6.8′	E1
NGC-4526		0	12h 34.0m	+ 7°42′	9.6	7.2′x2.3′	E7
NGC-4535		§B	12h 34.3m	+ 8°12′	9.8	6.8′x5.0′	S(B)c
NGC-4536		§	12h 34.5m	+ 2°11′	10.4	7.4′x3.5′	Sc
NGC-4552	M-89	0	12h 35.7m	+12°33′	9.8	4.2′x4.2′	E0
NGC-4567		§	12h 36.5m	+11°15′	11.3	3.0′x2.1′	Sc
NGC-4569	M-90	§	12h 36.8m	+13°10′	9.5	9.5′x4.7′	Sb$^+$
NGC-4579	M-58	§	12h 37.7m	+11°49′	9.8	5.4′x4.4′	Sb
NGC-4594	M-104	§	12h 40.0m	−11°37′	8.3	8.9′x4.1′	Sb$^-$
NGC-4621	M-59	0	12h 42.0m	+11°39′	9.8	5.1′x3.4′	E3
NGC-4649	M-60	0	12h 43.7m	+11°33′	8.8	7.2′x6.2′	E1
NGC-5170		§	13h 29.8m	−17°58′	11.8_B	8.1′x1.3′	Sb
NGC-5364		§	13h 56.2m	+ 5°01′	10.4	7.1′x5.0′	Sb$^+$
NGC-5746		§	14h 44.9m	+ 1°57′	10.6	7.9′x1.7′	Sb

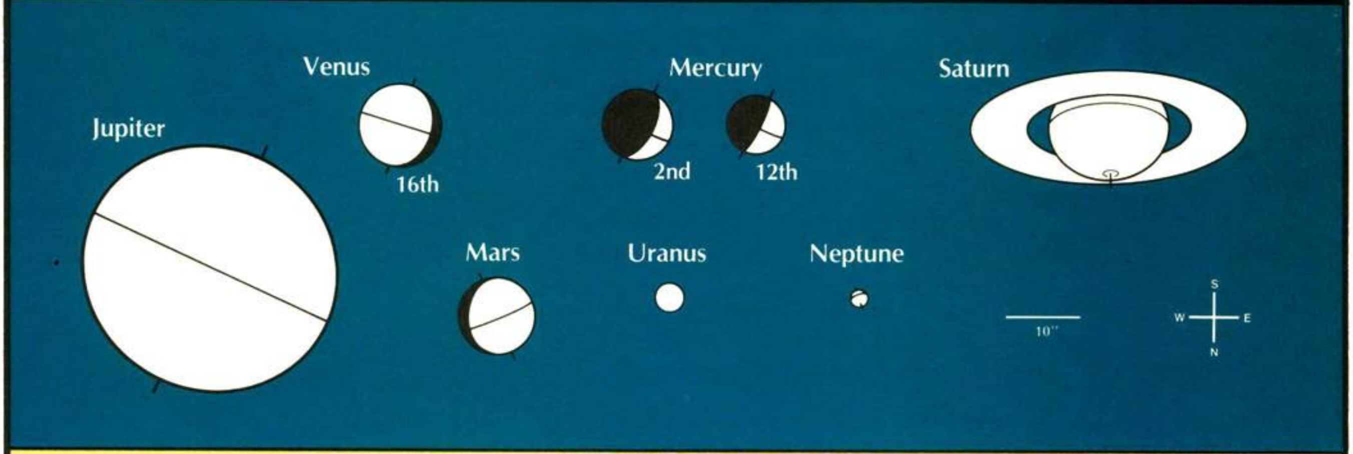
H = Hubble classification type for galaxies

§	*Sprial Galaxy*
§B	*Barred Spiral Galaxy*
0	*Elliptical Galaxy*
QSO	*Quasar*


14h
13h
12h
COMA BERENICES
M-90
M-86
M-84
NGC-4216
M-89
M-59
M-87
M-58
M-60
NGC-4567/8
ε
+10°
NGC-4535
M-49
NGC-4526
σ
NGC-5364
M-61
δ
NGC-4536
3C 273
0°
ζ
γ
η
θ
-10°
Ecliptic
α
M-104
CORVUS
NGC-5170
-20°

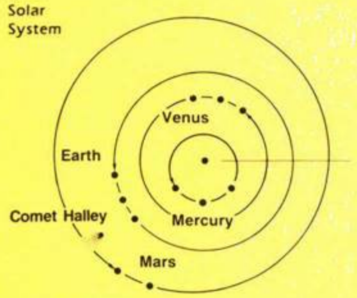
Planetary Data

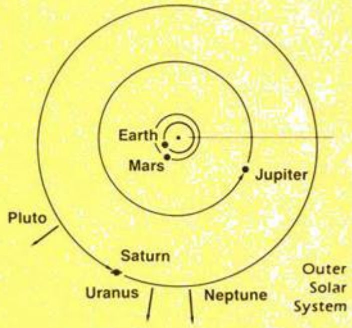
April 1986


Venus
16th
Mercury
2nd
12th
Saturn
Jupiter
Mars
Uranus
Neptune
10''
S
W
E
N

		Date	Mag.	Angular Size	% Illum.	Distance (AU) from: Earth	Sun	Longitude: Heliocentric	Ecliptic	R.A. (2000.0)	Dec.
Sun		1	−26.7	32.1′	—	1.00	—	—	10°58.6′	0h 41.0m	4°25.0′
		15	−26.7	31.9′	—	1.00	—	—	24°44.7′	1h 32.4m	9°39.2′
		30	−26.7	31.8′	—	1.01	—	—	39°22.1′	2h 28.6m	14°40.5′
Mercury	☿	1	1.2	9.7″	25%	0.69	0.45	227°36.5′	348°25.0′	23h 16.7m	− 4°36.5′
		15	0.4	7.6″	50%	0.89	0.47	266°38.9′	357°24.6′	23h 54.1m	− 3°08.2′
		30	−0.2	6.1″	71%	1.11	0.42	311°50.8′	17°24.6′	1h 08.2m	4°23.7′
Venus	♀	1	−3.9	10.4″	96%	1.61	0.72	52°45.4′	28°32.5′	1h 46.9m	10°22.7′
		15	−3.9	10.7″	93%	1.56	0.72	75°16.3′	45°46.0′	2h 53.2m	16°31.6′
		30	−3.9	11.1″	91%	1.50	0.72	99°30.1′	64°06.2′	4h 07.9m	21°35.5′
Mars	♂	10	0.0	9.9″	89%	0.95	1.53	236°49.3′	276°27.4′	18h 28.2m	−23°40.1′
		20	−0.3	10.9″	89%	0.86	1.52	242°01.0′	280°55.0′	18h 47.7m	−23°42.2′
Jupiter	♃	15	−2.1	34.5″	100%	5.70	5.01	334°26.2′	342°23.7′	22h 56.5m	− 7°46.0′
Saturn	♄	15	0.2	17.9″	100%	9.24	9.99	245°05.9′	249°18.3′	16h 31.9m	−19°51.9′
Uranus	⛢	15	5.6	3.8″	100%	18.58	19.14	259°41.8′	262°16.9′	17h 27.0m	−23°18.3′
Neptune	♆	15	7.9	2.2″	100%	29.91	30.25	274°00.0′	275°53.5′	18h 25.9m	−22°12.9′
Pluto	♇	15	13.7	0.1″	100%	28.78	29.73	215°53.4′	216°28.1′	14h 38.9m	2°29.6′

Inner Solar System

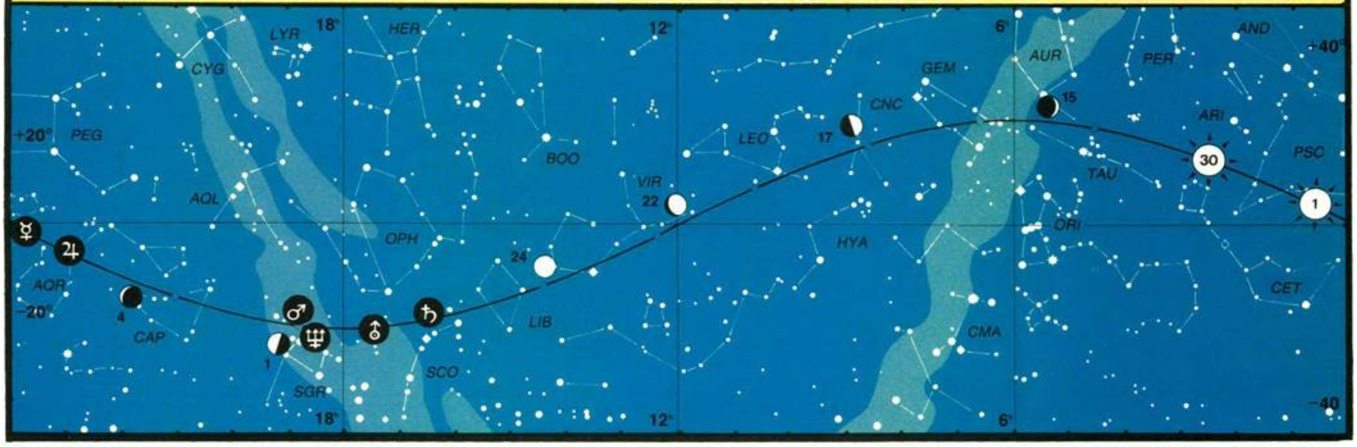

Venus
Earth
Comet Halley
Mercury
Mars

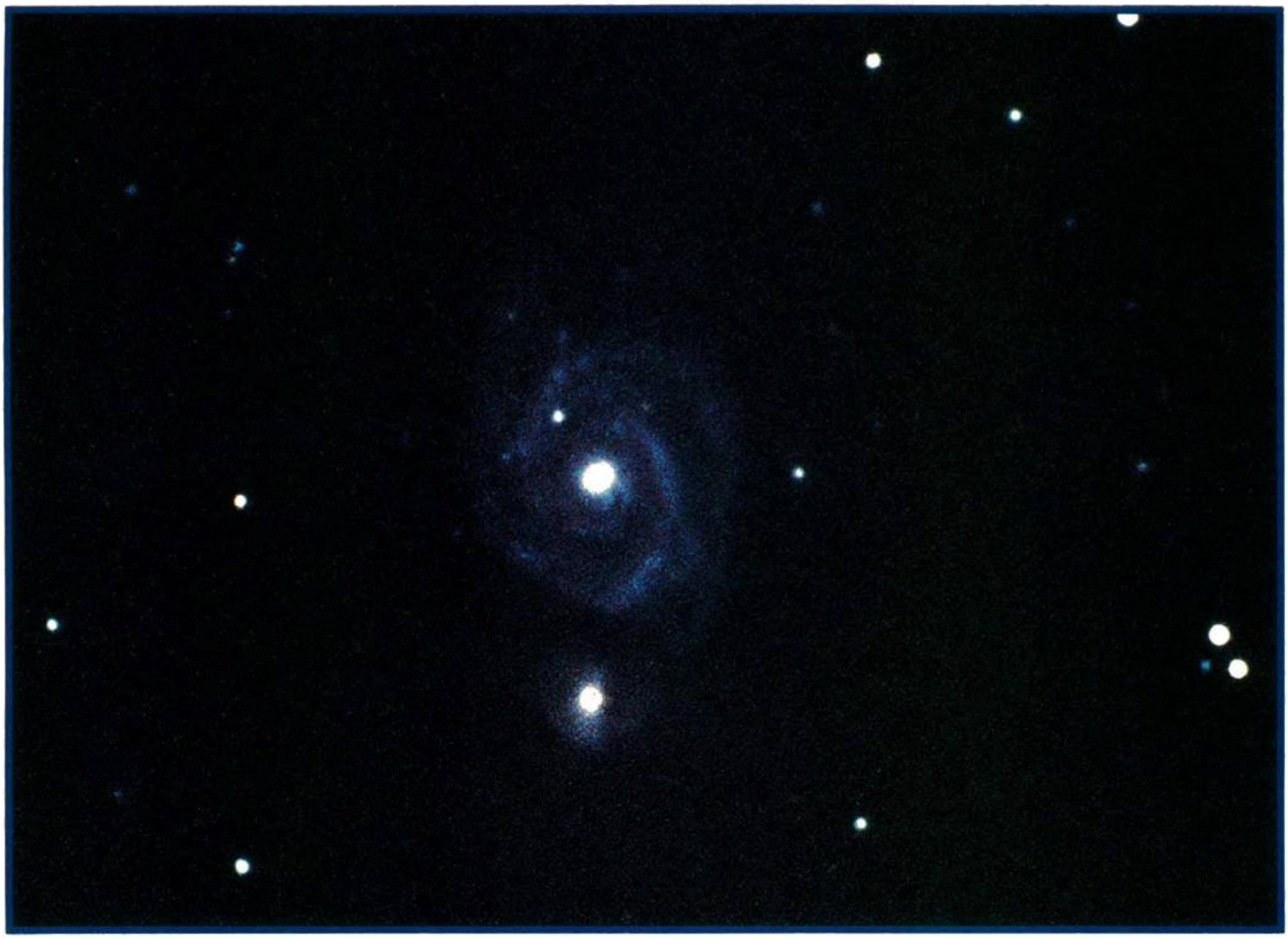

Earth
Mars
Jupiter
Pluto
Saturn
Uranus
Neptune

Outer Solar System

Moon Data

Last Quarter . . . . April 1 at 19h30m
New Moon . . . . April 9 at 6h08m
First Quarter . . . . April 17 at 10h35m
Full Moon . . . . April 24 at 12h46m
Last Quarter . . . . May 1 at 3h22m
New Moon . . . . May 8 at 22h 10m
Apogee: April 13 at 12h01m . . . 405,519 km.
Perigee: April 25 at 17h41m . . . 359,352 km.


LYR
18°
HER
12°
6°
AUR
AND
+40°
CYG
GEM
PER
CNC
15
ARI
+20°
PEG
LEO
17
BOO
TAU
30
PSC
VIR
22
AQL
1
ORI
OPH
HYA
24
AQR
−20°
CET
4
CAP
LIB
CMA
1
SCO
SGR
18°
12°
6°
−40



To make this photo of M-51 and its small companion galaxy NGC-5195, Andrew Steinbrecher used a 16-inch telescope, Agfa 1000 slide film, and a 28-minute exposure at f/5.5.

Mercury

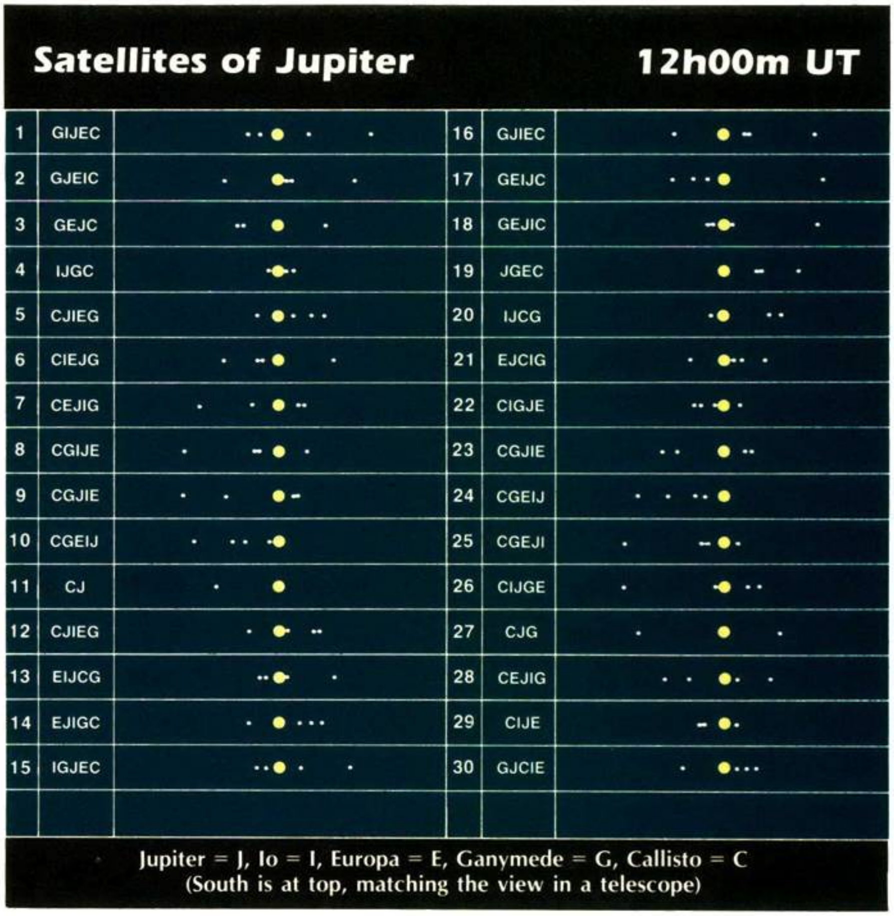
Although Mercury reaches greatest western elongation from the Sun this month (April 13th, 28°), the ecliptic forms such a shallow angle to the eastern horizon that, forty-five minutes before sunrise on the date of elongation, the planet's elevation will amount to only 2°. This is one of the year's worst apparitions of Mercury for observers in the Northern Hemisphere.

Venus

Although best viewing of Venus in the evening sky during the current apparition will come in June when the planet reaches an elevation of 18° forty-five minutes after sunset, viewing is not bad this month. Brilliant white Venus will be easy to locate low in the west as the sky darkens after sunset. You'll find that viewing the planet's almost-round disk in your telescope is better if you observe before the sky darkens too much. This will reduce the glare from the bright planet and also place it higher so that distortions from the atmosphere are lessened.

Moon

On April 9th, the Moon will partially eclipse the Sun as seen from Australia, the



Satellites of Jupiter 12h00m UT

1	GIJEC	16	GJIEC
2	GJEIC	17	GEIJC
3	GEJC	18	GEJIC
4	IJGC	19	JGEC
5	CJIEG	20	IJCG
6	CIEJG	21	EJCIG
7	CEJIG	22	CIGJE
8	CGIJE	23	CGJIE
9	CGJIE	24	CGEIJ
10	CGEIJ	25	CGEJI
11	CJ	26	CIJGE
12	CJIEG	27	CJG
13	EIJCG	28	CEJIG
14	EJIGC	29	CIJE
15	IGJEC	30	GJCIE

Jupiter = J, Io = I, Europa = E, Ganymede = G, Callisto = C
(South is at top, matching the view in a telescope)

Right: IC 1396 is an emission nebula in Cepheus. Andrian New of San Antonio, Texas, wins the "Best Astro-Photo" award for April with this shot taken in October 1985. He used an 8-inch f/1.5 Schmidt camera, 103a-E spectroscopic film, and a 30-minute exposure through a Wratten #29 red filter. Left: On January 8 Geoff Chester made this photo of Halley's Comet.

South Island of New Zealand, and parts of Indonesia, New Guinea, and Antarctica.

Half a lunation later (on the 24th), the Moon passes almost through the center of the shadow-cone of the Earth, producing a total lunar eclipse. Unfortunately for North American viewers, the most favored region for observing the eclipse is the Pacific Ocean. Hawaiian observers benefit splendidly: the eclipse will "turn off" the Full Moon and display Comet Halley. As seen from the West Coast, however, the Moon enters totality (at 12h10m UT) when it is nearly setting.

Mars

Despite being several months from opposition, Mars' apparent size and brightness are increasing rapidly. During April, the planet's disk will swell from 9.0" across to 12.1" and its brightness will increase from 0.1 magnitude to −0.6, a factor of two. Between now and opposition in mid-summer, observe Mars at every opportunity, for there's no better way of educating your eye to pick out all the detail that the planet offers.

Minor Planets

1 Ceres (magnitude 7.2) lies in north-central Leo; it is stationary in right ascension on April 19th. Its positions:

1st: 10h 44m 58s, 25° 07.6′
10th: 10h 41m 28s, 24° 45.6′
20th: 10h 40m 07s, 24° 01.5′
30th: 10h 41m 25s, 23° 00.8′

Ceres transits the meridian about 9:15 p.m. local time on April 15th.

2 Pallas (8.4) is moving eastward in central Monoceros. Its positions:

1st: 6h 28m 52s, −5° 23.2′
10th: 6h 43m 04s, −2° 53.3′
20th: 7h 00m 06s, −0° 26.4′
30th: 7h 18m 12s, 1° 39.0′

Pallas sets around 10 p.m. local time on the 15th.

3 Juno (10.7) lies in central Ophiuchus. Its positions:

1st: 17h 08m 15s, −8° 16.4′
10th: 17h 08m 24s, −7° 32.1′
20th: 17h 06m 33s, −6° 41.0′
30th: 17h 02m 37s, −5° 50.3′

Juno rises about 11 p.m. local time on the 15th.

4 Vesta (8.0) is in eastern Aquarius, near the stars ψ^1, ψ^2, ψ^3 Aqr. Its positions:

1st: 22h 29m 26s, −12° 48.6′
10th: 22h 46m 06s, −11° 28.5′
20th: 23h 04m 02s, −10° 00.4′
30th: 23h 21m 18s, − 8° 34.6′

Vesta rises around 4 a.m. local time on the 15th.

7 Iris (10.5) is moving retrograde in Virgo to the southeast of Spica. Its positions:

1st: 13h 53m 31s, −18° 47.3′
10th: 13h 45m 34s, −18° 04.0′
20th: 13h 36m 09s, −17° 04.0′
30th: 13h 27m 08s, −15° 58.1′

At opposition on April 16th, Iris is visible all night long.

To locate a minor planet, plot its dated positions (given for 0h UT) lightly in pencil on a good star atlas (*Sky Atlas 2000.0*, for example) and sketch a smooth curve linking the points. Then observe the starfield at low magnification and photograph or plot by hand what you see. Check the field a night or two later; the "star" that moved is it. (All minor planet coordinates are for the epoch 2000.0.)

Jupiter

By the middle of April, Jupiter will be 9° high in the southeast as twilight begins to lighten the sky. Though the planet remains low most of the month, you may want to start observing Jupiter now to accustom your eye to its features.

Saturn

Rising in the late evening, Saturn is a prominent object for telescopes in the midnight sky. For observing details, see Gazer's Gazette on page 89.

Uranus

Uranus lies about a degree north of the 4.2-magnitude star 44 Ophiuchi (see the finder chart on page 107 of the January 1986 issue). The planet has a 5.6-magnitude disk that will look bluish green and measures 3.8" across.

Neptune

To locate Neptune, use the finder chart on page 107 of the January issue or, if you're observing around April 8th, you can use Mars. At 21h42m UT on the 8th, Mars lies 1° 27′ south of Neptune; scanning north from bright Mars to dim Neptune will be very easy. Neptune will have a brightness of 7.9 magnitude and will display a grey-green disk measuring 2.2" across.

Pluto

Pluto reaches opposition to the Sun on April 26th; at that time, the planet lies 28.762 astronomical units (4.314 billion kilometers) from Earth. (See the finder chart in the January issue.)

Meteors

Two meteor showers occur in April: the Virginids, which reach peak activity, of sorts, on April 12th, and the Lyrids, which peak on the 22nd.

The Virginids actually include several streams with radiants in Virgo near Spica. They have an average zenithal hourly rate of about 10; this year's display ought to be good since the crescent Moon will set soon after the Sun, leaving the sky dark.

The prospects for the Lyrids aren't as good since their peak comes just two days before Full Moon; observers can expect interference from moonlight almost all night long. The meteors' radiant lies near the Lyra-Hercules border; their zenithal hourly rate is about 15.

Comet Halley

Observing the comet this month is a touch-and-go matter that's highly dependent on your latitude and weather. It is essential that you find a dark-sky site with a low, preferably flat, southeastern and southern horizon. At the beginning of the month, the comet lies below the tail of Scorpius and rises shortly before twilight begins (see the Gazer's Gazette in last month's issue).

By the middle of April, Halley will have moved westward into Centaurus and is best visible by about 11 p.m.; look low above the southern horizon. Moonlight starts to interfere around the 16th, but keep observing as long as you can. This is the last good view of Halley you'll get for another seventy-six years.

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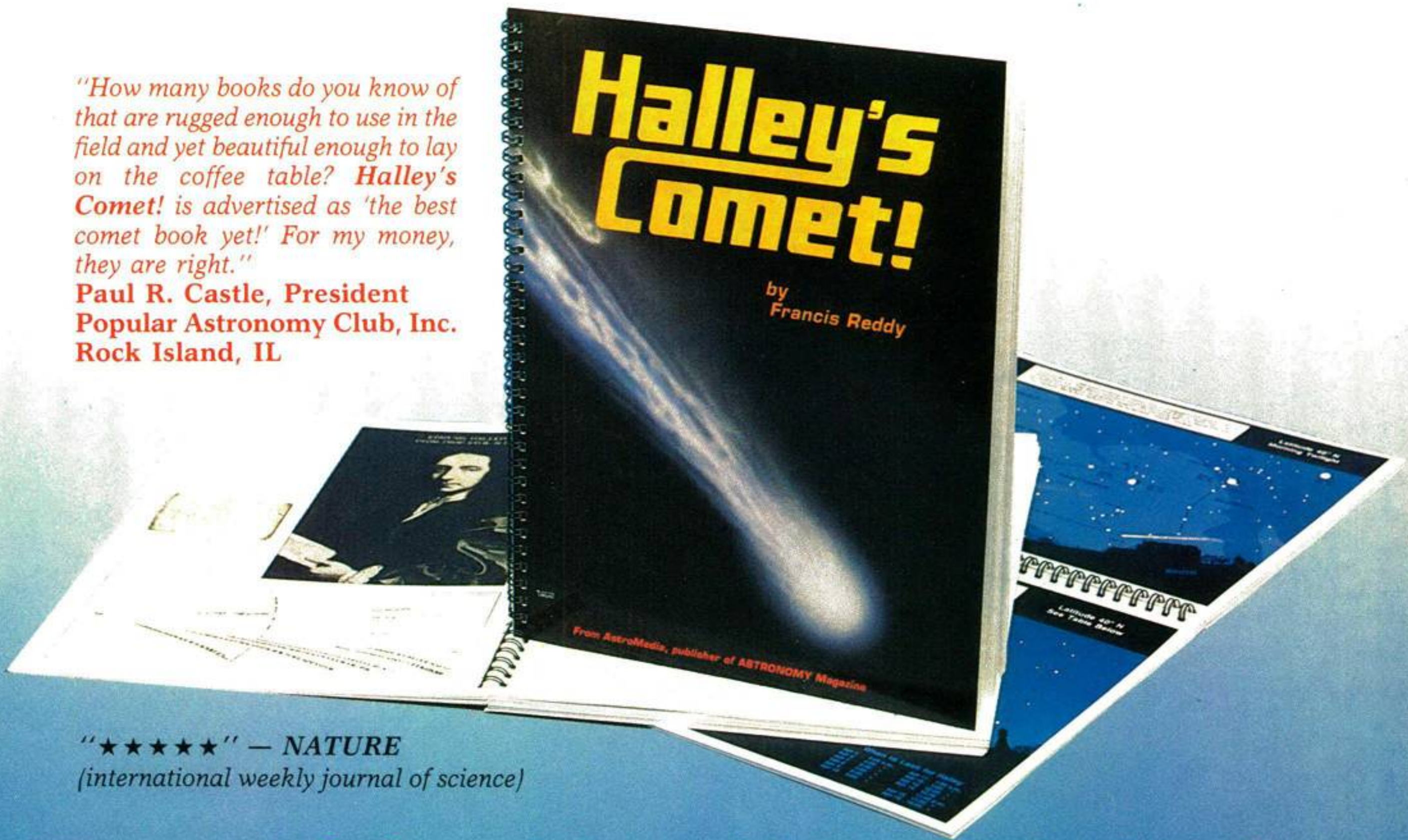
Paul R. Castle, President
Popular Astronomy Club, Inc.
Rock Island, IL



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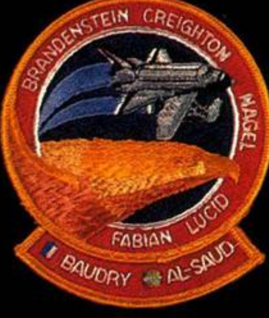
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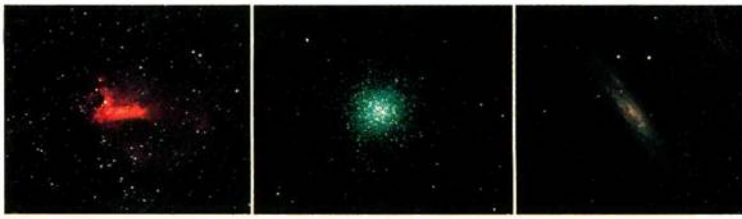

C8 Astrophotographs: M-17, Omega Nebula; M-13, Globular Cluster; NGC-253.

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